TRANSACTIONS
American Society for Steel Treating

VOL. XVII JANUARY, 1930 NO. 1

LOCOMOTIVE FORGINGS

By LAWFORD H. FRY

Abstract

The production of locomotive forgings which will give good results in service necessitates the employment of correct methods from the melting of the steel to the finished forging. The various steel melting processes are discussed and compared. The importance of ingot structure is considered. The forging process is described and the resulting structures of steel forgings illustrated by photomicrographs. The author enumerates the various types of forging steels. The necessity of heat treatment is pointed out and a discussion is given of the physical properties which may be expected of forging steels.

THE problem of providing satisfactory forgings for locomotive parts such as connecting rods, crank pins, axles and piston rods is receiving much attention at the present time. Railroad officials and manufacturers are alive to the importance of providing the best possible material and the specifications committees of the American Railway Association and of the American Society for Testing Materials have before them proposed new specifications, which represent considerable advances over the requirements that were standard from 1913 to 1926.

Several factors have contributed to direct attention to the necessity for providing forgings of high quality for locomotives. The trend has been toward locomotive units of larger power and in some designs this has gone so far that each piston rod and main rod must transmit to the main crank pin a thrust as high as 165,000 pounds.

A paper presented before the Eleventh Annual Convention of the Society, Cleveland, September 9 to 13, 1929. The author, Lawford H. Fry, is metallurgical engineer, Standard Steel Works Co., Burnham, Pa. Manuscript received April 26, 1929.

Forgings so loaded must have not only size but also quality. Size cannot be increased indefinitely because of limits of weight and constructional requirements. Coupled with the increase in load to be carried has come more intensive service for the locomotives and greater insistence on freedom from engine failures.

Present day demands are such, that to produce locomotive forgings which will give good results in service the manufacturer must consider a wide range of problems. It is not enough to concentrate on the process by which the forging is shaped out of a block of steel, and then to see that this is followed by a careful heat treatment, so that on inspection the specified tensile properties are obtained. To secure satisfactory forgings control of the process must begin much earlier. Proper methods must be chosen for the making of the steel. The molten steel must be cast in correctly designed ingot molds. The ingots when cast must be allowed to solidify properly and must be carefully reheated and worked into the billets which go to the forge shop. Correct methods in these preliminary processes are of vital importance to the quality of the finished forgings. In fact the way in which the steel is handled before it reaches the forge shop proper, determines whether or not it can be made into a satisfactory forging.

For example consider the bloom shown in Fig. 1. This figure shows an etched section from the end of a rolled steel bloom produced on a tonnage basis and sold to railroads or forging manufacturers to be used for making locomotive rods. The end appeared solid before etching, but the acid test brings out the very decided lack of homogeneity in the steel. If this bloom were shaped up into a rod it would be quite possible that an acceptance tensile test might be taken from the sounder portion of the steel so that the specification requirements would be met. The rod itself as a whole would, however, be undesirable for high duty service.

Manufacture of Steel

This is not the place to write a treatise on the manufacture of steel, but it is pertinent to the subject to note some of the principles which affect the quality of the steel to be used by the forging maker.

The majority of steel used for locomotive forgings is made by the open-hearth process. The electric furnace is used for a comparatively small tonnage, but because of certain advantages is becoming increasingly important. It is in principle an open-hearth furnace,

Fig. 1—Photograph of Undesirable Forging Bloom. Piping and Porosity Shown by Deep Etching.

the only difference being that the heat for melting and refining the charge is supplied electrically instead of by the combustion of gas or oil. It offers to the skilled steel maker an excellent tool for the production of high quality steel, but the electric current possesses no esoteric virtue which will of itself prevent the production of poor steel. As with all good tools a skilled workman is necessary to obtain satisfactory results.

In the flame-heated open-hearth furnace two processes, the basic and the acid, are used, which differ in the chemical reactions set up. The fundamental principles are however the same in both. The furnace consists of a slightly hollowed bath or hearth on which the charge is placed and over which the flame sweeps. The charge is made up of pig iron and scrap steel in proportions to suit local conditions. As the charge melts it becomes covered with a layer of molten slag, and during the refining operation the flame sweeps over this blanket of slag without coming into direct contact with the molten steel and the refining processes take place between the flame and the slag and between the slag and the steel.

To make clear the processes involved, a word as to the final composition of steel is needed. For the sake of simplicity a plain carbon forging steel will be considered. When finished the composition of the steel, as shown by the ordinary routine specification analysis, will be about as follows—carbon, 0.45 to 0.55 per cent; manganese, 0.55 to 0.70 per cent, and silicon, 0.15 to 0.25 per cent.

These elements are essential to the strength and solidity of the steel and the proportions shown are appropriate to good forging steel. Phosphorus and sulphur will be present as impurities and are usually specified not to exceed 0.05 per cent for each element.

In the present state of our knowledge the five elements named are all that can be covered by a chemical specification for carbon steel. Unfortunately, although they are important in determining the strength and solidity of the steel, they do not measure completely its quality. It is this which rates steel making as an art and not a science. The quality of the steel as measured by the final proof of service, is dependent on certain processes in the manufacture which are controllable only by the skill of the open-hearth melter, and for which no scientific check has yet been developed. Further, when the steel is made, a well made heat and a poorly made heat may have the same composition so far as the five specified elements are concerned and may be indistinguishable one from the other by existing methods of routine chemical analysis. Yet in service one heat may give good and the other very poor results. In the manufacture of high quality forgings it is essential to have a skilled and conscientious steel maker controlling the source of supply.

In the processes of the manufacture, the charge of pig iron and scrap steel from which a melt of steel is to be made, will, when charged into the open-hearth furnace, contain more carbon, silicon and manganese than are to appear in the finished steel. When melted the charge will also contain a considerable quantity of undesirable oxides, partly from the original charge and partly due to oxidization of the iron of the charge during the melting period. The amount of oxide in the bath will depend on the care taken in selecting the charge and in the skill used in controlling the melting. Badly rusted scrap puts in a lot of oxide to start with and thin finely divided scrap offers a chance for excessive oxidization by the flame during melting. The extent to which the oxide is removed during the refining process will determine the quality of the finished steel.

High quality steel requires a selected charge and care in the elimination of oxides during refining. In this refining operation, which really constitutes the making of the steel, the silicon and manganese in the bath burn away, that is, they take up oxygen from the iron oxide in the bath and slag, and from iron ore added for the purpose. The oxides resulting from this burning rise through the bath and are in part transferred to the slag. The carbon also burns out, but somewhat more slowly. When the oxides have been satisfactorily removed from the bath and when the carbon has been brought down to the desired point, the final additions are made, namely, manganese and silicon are added. The effect of these additions is to carry out a final deoxidization and to "kill" the steel, that is, to drive off or absorb gases which the steel would otherwise contain. Without these final additions the steel would be highly effervescent when poured into the molds, and would, when cold, be found to contain numerous blowholes. The additions must contain sufficient manganese and silicon to allow for the final deoxidization and still leave in the steel the amount of these elements indicated above.

So far as the manganese and silicon content is concerned the final addition of these deoxidizers may be made in the furnace just before tapping, or in the ladle as the steel is poured in. The choice between the two methods of addition will depend on whether economy in cost of production or high quality is given preference. If the additions are made in the furnace more manganese and silicon must be used to obtain the same quantity in the steel, but the desired reactions take place more completely and there is more opportunity for the undesirable products of these reactions to free themselves from the steel and be carried off in the slag. If the additions are made in the ladle the process is slightly cheaper but there is less certainty of obtaining steel of satisfactory quality.

The same is true in respect to carbon, but in a more marked degree. During the refining process the steel loses carbon slowly. To make good steel the process should be so controlled that the steel can be tapped out of the furnace just as the carbon content reaches that desired in the finished steel. If the carbon falls too low before tapping, it is possible, so far as composition is concerned, to recarburize by adding pig iron in the furnace or even by adding fine anthracite coal as the steel goes into the ladle. This will raise the carbon con-

tent, but is detrimental to the quality of the steel. There is no certainty of uniform reactions throughout the steel and undesirable reaction products may be retained. In making steel for use in high quality forgings no pig iron should be added in the furnace after the bath is melted, and recarburizing in the ladle should never be permitted. In open-hearth language the carbon should be "caught coming down." It is also desirable that after the addition of the last lot of ore to the bath a period of at least two hours should elapse. These precautions are designed to permit the bath to free itself as far as possible of oxides and nonmetallic reaction products. A recent paper by Pierce[1] shows how recarburization increases the number of nonmetallic inclusions.

The principles which have been laid down apply generally to all open-hearth practice, whether the acid or the basic process is used. It has been pointed out that these two processes differ in the chemical reaction involved. This difference is brought about by the refractory materials used to form the furnace walls and the hearth on which the molten metal lies. The furnace itself is a steel structure lined with refractory material to protect it from the intense heat of the furnace chamber in which the steel is melted. In the basic furnace the refractory lining is magnesite or dolomite. The former is largely magnesia while the latter is a mixture of lime and magnesia. With these linings lime can be added to the slag, bringing it into what the chemists call a basic condition. This basic slag has the valuable property of being able to absorb phosphorus from the molten steel. Therefore the pig iron or scrap of the charge may have a high phosphorus content and this can be reduced during refining so as to give the low phosphorus content required by the specification. In this country the iron ores producing high phosphorus pig iron are more numerous than those which will produce low phosphorus pig iron. The basic open-hearth process which permits the use of iron of any phosphorus content makes available for the manufacture of steel, ore deposits which could not otherwise be used.[2] It has thus become the most widely used steel making process in this country.

For many grades of steel such as structural shapes, rails, etc., the basic process gives perfectly satisfactory results. For special purposes though, such as the manufacture of forgings of high qual-

[1]Pierce, *Journal*, Iron and Steel Institute, Vol. CXVII, 1929, p. 63.

[2]J. M. Camp and C. B. Francis, "The Making, Shaping and Treating of Steel," 1925, p. 200. Carnegie Steel Company.

ity, the acid open-hearth process has important advantages. In the acid open-hearth the furnace lining is of silica and the resulting slag is of an acid nature. Lime cannot be added in any quantity as it would flux or dissolve the silica furnace lining. As a consequence phosphorus cannot be removed from the charge and the charge for an acid furnace must be made up of carefully selected low phosphorus pig iron and scrap. The silica lining and the high silica content of the slag in the acid open-hearth process aid in the reduction of oxides in the steel during refining so that in comparison the basic process falls short in not giving equal facilities for deoxidization.[3] It is characteristic of the acid process that the slag, which is a dull dirty black color when the steel is first melted, gradually changes color as the oxides are removed during refining and finally in a well made heat takes on a clear olive green color. This change can be easily followed by an experienced steel maker.[4] No such change occurs in the basic slag. For high grade forgings subject to more than ordinarily severe tests the superiority of acid over basic has been repeatedly proven not only in this country but also in England and France. The reason for this superiority is the greater freedom from oxides obtainable in acid steel. The acid slag is a more effective deoxidizing agent than the basic slag so that well made acid steel can be made with fewer oxide inclusions than will be found in equally well made basic steel.[5]

After being finished in the furnace the steel is tapped into a ladle from which it is poured into the molds. It is good practice to let the steel stand in the ladle from ten to twenty minutes before pouring it into the ingot molds. During this time the larger particles of slag or dirt which may have been entangled in the steel have an opportunity to rise to the surface. At the end of the holding time the steel is poured through a nozzle in the bottom of the ladle into the ingot molds. Pouring may be done directly into the open top of the mold or through a firebrick runner connected to the bottom of one or more molds. Ingots of good quality can be poured by either method. Each has some advantages, but in the writer's opinion the balance is slightly in favor of top pouring. The temperature of the

[3]W. H. Hatfield, "The Application of Science to the Steel Industry," TRANSACTIONS, American Society for Steel Treating, Vol. XV, March, 1929, p. 474.

[4]Radclyffe Furness, "Acid Open-Hearth Steel Melting Practice," TRANSACTIONS, American Society for Steel Treating, Vol. VIII, December, 1925, p. 728.

[5]De Mare, "Notes on the Acid Open-Hearth Process," *Blast Furnace and Steel Plant*, Vol. VIII, June, 1920, p. 318.

steel during pouring is of importance, and must be controlled by the melter to suit the kind of steel and type of ingot in question. These and other details of the manufacture of steel are dealt with here, not with a view to providing a manual of practice for steel makers, but to call the attention of forging makers and forging users to some of the factors which affect the quality of forgings.

Structure of Ingots

A strong influence on the structure of the forgings is exerted by the conditions under which the molten steel solidifies in the ingot. These conditions which deserve careful consideration are beyond the control of the steel maker except insofar as they are determined by the choice of the size and design of the ingot mold into which the molten steel is cast.

In approaching a study of the structure of forgings as affected by the structure of the ingot it must be borne in mind that the steel solidifying in the ingot mold does not form a uniform structureless solid like a jelly. It freezes, on the contrary, as water does with crystals forming first at the coldest points and growing gradually as the liquid metal cools. The effect that this method of freezing has on the ingot structure is increased by the fact that the steel contains a number of constituents which freeze at different temperatures.

Another important factor influencing the ingot structure is the contraction or shrinkage of the metal during solidification. In an open top mold the steel will solidify on all exterior surfaces and the subsequent solidification and shrinkage of the interior will leave a cavity or "pipe" down the center of the top portion of the ingot. This may require the top third of the ingot to be discarded to insure the use of sound steel only. There is considerable advantage in using an ingot mold of the "hot-top" type producing an ingot such as is shown in section in Fig. 2. In this type of ingot the steel in the upper part has its solidification delayed by using a collar of refractory material to keep the steel from being chilled by contact with the iron mold, and by covering the top surface of the steel with powdered coal or a similar material. With this arrangement the steel in the top remains molten and fills up any space left by the shrinkage during cooling of the steel in the bottom of the ingot. The final solidification leaves a slight depression at the top instead of a deep central pipe.

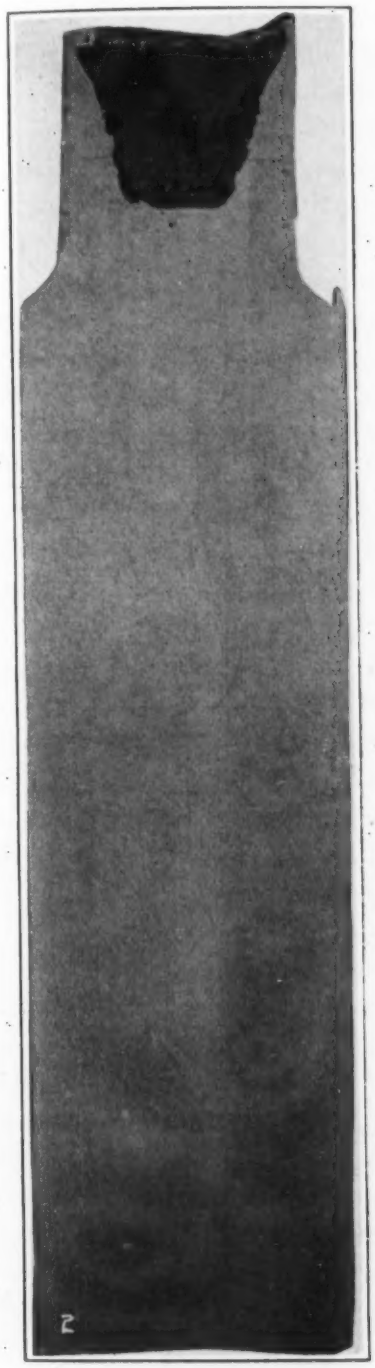


Fig. 2—Photograph of Section of Hot-Top Forging Ingot. All Piping is Confined to the Hot-Top, Reducing Discard Loss to a Minimum.

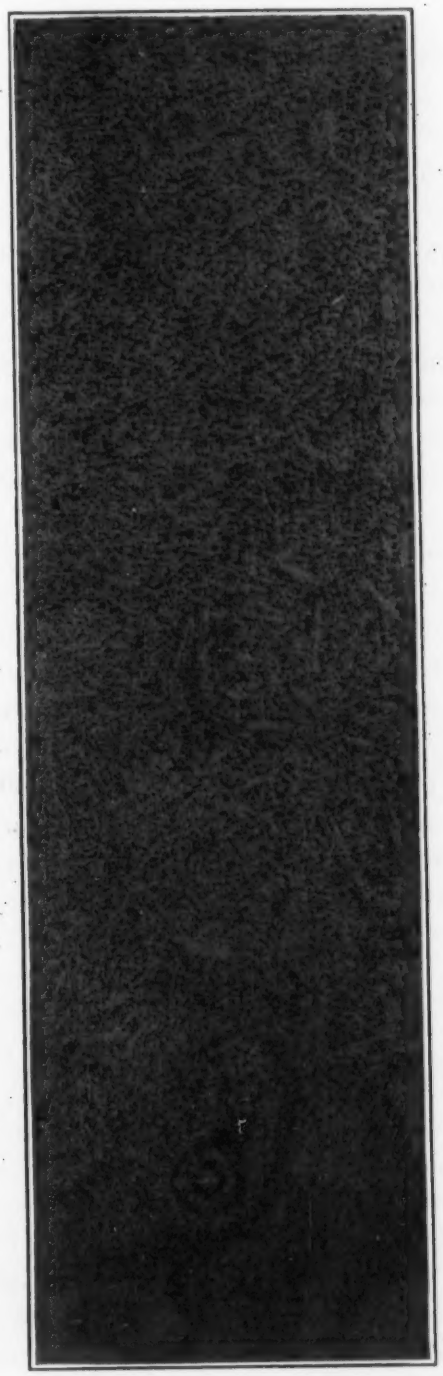


Fig 3—Sulphur Print from Outer Portion of Axial Section of a Forging Ingot. Outer Surface of Ingot at Bottom of Cut.

By etching the central longitudinal section of ingots it is possible to see the structure due to the crystallization of the steel during solidification. The question has been studied extensively by a committee of the Iron and Steel Institute[6] under the chairmanship of Dr. W. H. Hatfield, whose very valuable paper to the American Society for Steel Treating last year summarizes much of the work of the committee. This paper has been already quoted and will be quoted again. In discussing the work of his committee Dr. Hatfield says, "When steel freezes it does so by differential freezing. Consequently no ingot is uniform in composition." This lack of uniformity or segregation of the constituent elements may be recognized in two forms. First, what may be called major or primary segregation. This is observed when samples of appreciable weight, say 10 grams, (⅓ ounce) are taken from various portions in the ingot and the chemical composition of each sample is determined. The composition of the samples will vary with the position from which they are taken. As the top central portion of the ingot is approached the proportion of carbon, phosphorus and sulphur will increase. The second form of segregation, minor or secondary segregation, consists of slight variations in composition between closely adjacent portions of steel. To detect it, more delicate methods of determining composition are necessary. The methods usually employed are sulphur printing or etching. Either of these methods magnifies the effect of slight variations of composition and brings into prominence differences which could hardly be detected by analysis.

For example Fig. 3 reproduces a sulphur print from the outer part of an axial section of an ingot. On the extreme outside can be seen traces of a light colored, noncrystalline skin. This is formed by the first chill of the outside metal. Growing in from this chill skin are to be seen light colored crystal forms, outlined with darker material. From the nature of a sulphur print we know that the darker portions are higher in sulphur, and we assume that they are also higher in carbon and phosphorus because the three elements segregate together. From a print of this sort the mechanism of freezing can be followed. The first crystals of steel which form at the coldest points on the sides of the ingot are comparatively low in the three segregating elements because these elements raise the melting point of steel. As the first crystals grow they make tree-like forms, called

[6] "Report of Committee on Heterogeneity of Steel Ingots," *Journal*, Iron and Steel Institute, Vol. CXIII, 1926, p. 39 and Vol. XCVII, 1928, p. 401.

"dendrites" from "dendron," the Greek for tree, and are surrounded by liquid metal higher in sulphur, phosphorus and carbon. As the crystals approach each other this liquid is entrapped between their branches and solidifies there.

The growth of these columnar crystals does not continue throughout the body of the ingot because, as will be seen later, another type of crystal growth is set up as the rate of cooling slows down. Nevertheless during the whole process of solidification crystals are forming of the purest metal available and are entrapping portions of the less pure liquid surrounding them.

As each layer of crystals is formed at the sides and bottom of the ingot it is slightly higher in sulphur, carbon and phosphorus than the layer outside it and its formation leaves the liquid metal still higher in these elements. The result is that in the solidified ingot the sulphur, carbon and phosphorus content increases progressively from the lower and outside portion which cools first, up to the top central portion which is the last to solidify. In fact in the zone of final solidification the segregation of the carbon, sulphur and phosphorus will be so high that the steel in this neighborhood will be unusable for quality purposes and a portion of the top of the ingot, the amount depending on the size and design of the ingot, must be discarded.

A closer study of the sulphur print from which Fig. 3 is made will throw light on the processes of solidification. Prof. C. Benedicks[7] distinguishes three separate phases in solidification, and evidences of these can be seen in the sulphur print. The three phases comprise:

1. Formation of thin skin of chilled metal.
2. Formation of thicker skin of columnar crystals growing generally perpendicular to wall of ingot mold.
3. Formation of irregularly placed or equiaxed crystals to make up the core of the ingot.

Considering these phases more in detail we have:

1. *Chilled skin.* When the steel is first poured into the mold the metal in immediate contact with the cold metal walls of the mold, solidifies very rapidly, forming a thin skin. Solidification is so rapid that there is no segregation of any elements and on etching or sulphur

[7]C. Benedicks, "Report of Committee on Heterogeneity of Steel Ingots," *Journal*, Iron and Steel Institute, Vol. XCVII, 1928, p. 558.

printing, no crystal formation is disclosed. If further solidification is delayed the chilled skin may be re-dissolved in the molten metal and may not appear in the final form of the ingot. When present, the skin is usually thin with numerous small blow-holes, and is generally removed during the rolling, forging and rough turning operations. In exceptional cases in which the skin is present in the finished product it constitutes a source of weakness because the bond between it and the remainder of the steel is easily broken.

2. *Columnar dendritic crystals.* These form on the cold walls of the ingot mold or on the inside of the chilled skin and grow inwards nearly perpendicularly. In the full size sulphur print they can be seen extending in about two to three inches with a slight upward trend particularly in the top portion of the ingot.

These columnar crystals develop during the first period of rapid cooling of the ingot. Dr. Benedicks states that their development ceases when the contraction of the steel causes the ingot to shrink away from contact with the sides of the ingot mold. When this separation between the ingot and the ingot mold takes place the rapid loss of heat from the ingot by conduction to the mold ceases and a slower rate of cooling by radiation from ingot to mold is set up. This leads to the third phase of solidification.

3. *Irregularly placed core crystals.* These according to Dr. Benedicks form in two ways, (a) by slow irregular growth on the inner surface of the columnar and (b) by the formation in the liquid metal of crystals which, being heavier than the liquid, fall slowly or "snow down" so to speak to the bottom of the mold. In many ingots the lower portion of the core shows a pyramidal structure evidently due to the accumulation of these falling crystals.

To sum up—the ingot, except for the thin chill skin which should be removed before the finished forging is reached, is composed of crystal growths surrounded by and enclosing metal of slightly higher sulphur content. This is minor segregation. The crystal growths are more or less regularly arranged in the outer portion and irregularly arranged in the interior of the ingot. Also in going through the ingot from the metal which froze first to that which solidified last it will be found that the average content of sulphur, carbon and phosphorus will rise. This is major segregation. The amount of both major and minor segregation is dependent on the size of the ingot. In a large ingot the cooling is slow, the crystals

grow to a large size. The difference between the composition of the crystal growths and the surrounding metal is greater than in a small ingot and there will be a very considerable difference in composition between the metal which solidifies first and that which solidifies last. In discussing this question of major segregation in his paper already quoted, Dr. Hatfield says:

> "This heterogeneity as regards composition is definitely found to increase with the mass of the ingot, so much so that in some of the largest ingots studied by the Committee, ingots weighing from 100 to 172 tons each, it can be safely said that the variation, particularly as regards the carbon content, is so considerable as to necessitate the designing engineer taking into consideration the effect of the variation in carbon on the strength of the material."

To complete the picture of the ingot structure some attention must be given to the nonmetallic inclusions which inevitably find their way into all steel. J. H. S. Dickenson[8] who has made a special study of these inclusions says:

"Every ladle of steel deoxidized by the addition of silicon and manganese or any other deoxidizer contains always an appreciable amount of the results of the deoxidizing reaction in the form of exceedingly fine globules of silicate too small in size to rise to the surface in the time available.

"Some slaggy matter may come from the refractories or from the furnace slag, but such extraneous matter can be reduced to a minimum by careful methods.

"The main source of slag specks found in ingots is the result of a reaction which cannot be avoided if sound steel free from blowholes is to be avoided."

Dickenson after considerable study of the inclusions is of the opinion that the maximum concentration of slaggy matter is found in the central lower part of the ingot just where, owing to the effect of segregation the carbon, sulphur and phosphorus content is reduced to a minimum. Though this tendency of the nonmetallic inclusions to concentrate in the lower central portion of the ingot is well established, no completely satisfactory explanation of the causes producing this concentration has yet been found.

This survey of the structure of the ingot serves to show that

[8] J. H. S. Dickenson, "A Note on the Distribution of Silicates in Steel Ingots," *Journal*, Iron and Steel Institute, Vol. CXIII, 1926, p. 178.

the making of the ingot will influence the character of a forging produced from it. During the mechanical process by which the ingot is shaped to a forging the original crystal structure will be distorted and modified and the shape of the nonmetallic inclusions may be changed, but the effect of the original ingot structure will be recognizable in the forging. One effect may be noted here. It is desirable to have in a forging a fine uniform crystal structure and uniform chemical composition. It has been pointed out that the larger the ingot the larger the crystal structure and the greater the diversity of chemical composition, therefore it is desirable to use an ingot no larger than is necessary. During the forging operation the grain size of the steel can be reduced and the patterns made by the crystal growths are elongated, but the variations in composition due to the minor segregation around the crystal growths are not eliminated. Consequently the fiber produced in the forging by the persistence of this minor segregation will be more marked if the original ingot is large.

Forging Process

The transformation from ingot to forging is brought about by mechanical working of the steel. In the case of the large locomotive forgings with which we are mainly concerned here there will usually be two steps. The ingot will be rolled or forged to a bloom or billet and this billet reheated and forged to shape. If tonnage production is important the ingot will be rolled to the billet form and time and fuel will be saved by transferring the ingot while still hot direct from the mold to a soaking pit or furnace, and holding it at a high temperature until it goes to the rolls. This processs involves the danger that the ingot may not be given time to solidify completely before being rolled. If this happens and the ingot is put through the rolls while the center portion is still semi-liquid the resulting billet will lack homogeneity and will not be adapted for the production of forgings of the best quality.

By allowing the ingot to cool to atmospheric temperature and then reheating for reduction to billet form the danger of an uncongealed core is avoided and quality is safeguarded, though at the expense of a slight increase in cost of manufacture.

Many billets for high quality forgings are produced by reheating cooled ingots and forging them to billet shape under a steam-hydraulic press. With this practice and with a sufficiently small ingot

the forging could be made direct from the ingot at one operation. Usually however a reheating will be necessary and in such cases it is good practice to forge to billet shape and to allow the billets to cool so that they can be inspected and any surface imperfections removed by chipping. This cooling and reheating has no particular metallurgical influence, providing that the processes are correctly carried out. The advantage is purely mechanical. By chipping out surface defects in the billet stage forgings with a better surface can be produced and it is not necessary to remove so much metal in machining.

To safeguard the quality of the forgings being made, attention must be given during the forging process to methods of heating and the temperatures at which the steel is worked. Heating must be gradual, uniform and thorough, particularly in the case of the ingot. At too high a temperature the steel will be injured, a so-called burnt structure resulting.

In order to reduce the grain size and facilitate the grain refinement in the heat treating process it is desirable for the final forging work to be done at a temperature not too far above the critical range but too great a forging reduction at a low temperature may cause internal tearing of the steel. The proper forging temperature will depend on the type of steel used, whether plain carbon or alloy, and on the forging to be made. To choose a satisfactory temperature for each type of steel used requires experience and constant vigilance. Here as in other subdivisions of the subject detailed instructions as to practice lie outside the scope of the present paper. All that can be attempted is to set up sign posts to show where care and experience are required.

In older specifications it is not unusual to find it required that the forgings shall be made from billets with a cross section not over one quarter that of the ingot and that a reduction of at least forty per cent in cross section shall be made from billet to ingot. With this requirement the ingot must have at least 6.5 times the cross section of the forging to be produced. This is unnecessary and may be undesirable. The committee on steel of the A. S. T. M. has made recently an extended experimental study of the effect of reduction between ingot and forging.

They concluded that in the low ratios of reduction a slight increase in physical properties could be obtained by increasing the

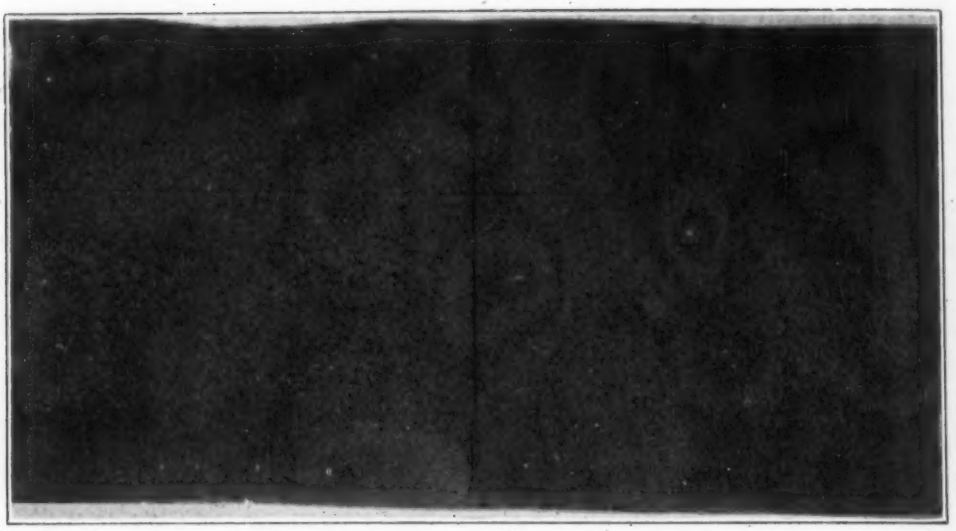


Fig. 4—Portion of Sulphur Print from a Central Longitudinal Section of a 12-Inch Square Bloom Forged Under a Hydraulic Press from an Ingot.

amount of reduction, but that this increase in physical properties was practically negligible when the ratio of reduction was carried beyond a value of about three to one. The experiments also indicated that it was immaterial whether the reductions were made between ingot and billet or between billet and forging.

Modern specifications are drawn to provide a reduction of at least three to one from ingot to forging. This has the advantage that in the large driving axles and connecting rods required by modern locomotives the forging manufacturer is not forced to use abnormally large ingots in which the secondary segregation may be excessive.

Structure of Forgings

As an example of the structure developed in a forging made from a moderate sized ingot the sulphur print shown in Fig. 4 is offered. This print is made from the central longitudinal section of a 12-inch square billet forged down under a steam-hydraulic press from a 23-inch ingot of the type shown in Fig. 2. The cross sectional area of the billet was approximately one third that of the ingot. The steel has received a forging reduction of three to one carried out at one heating. Some of the pattern of the structure produced by the original crystal growth of the ingot is to be seen, distorted of course by the forging operation. As the cross sectional area has been reduced all of the ingot structure has been elongated

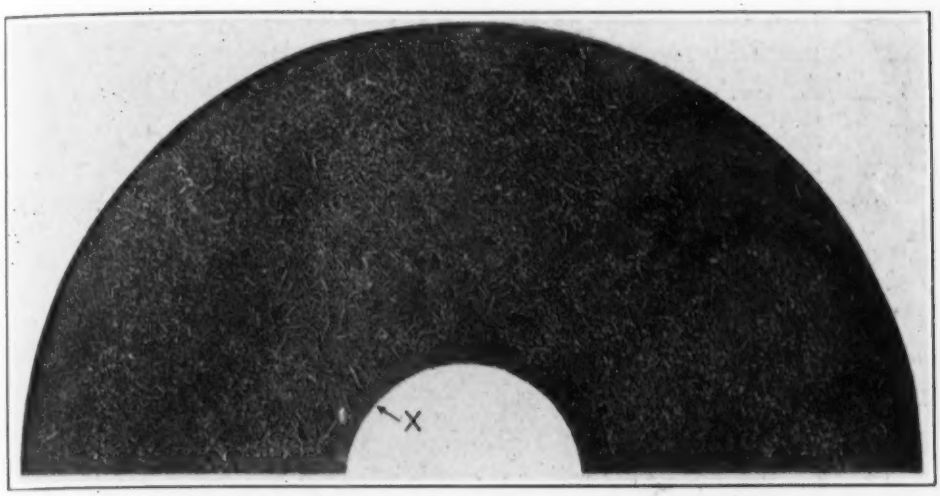


Fig. 5—Photograph of a Half Section of a Locomotive Crank Pin Showing the Pattern Remaining from the Original Ingot Structure.

in the direction of the longitudinal axis. The minute inclusions of slaggy material are not visible in the sulphur print, but microscopic observation shows that such of these inclusions as are plastic at the forging temperature are also elongated.

Another illustration of the persistence of the freezing pattern is given in Fig. 5 which shows a deeply-etched cross section of a 10-inch locomotive crank forged from a billet similar to that of Fig. 4. This pin has been quenched and tempered. In considering these patterns brought out by etching or sulphur printing forgings, it is important to understand that etching and sulphur printing both exaggerate greatly small differences in composition in steel and that the patterns obtained in forgings represent the outline of structures which have disappeared. They are only vestigal remains, ghosts, or as Dr. Hatfield calls them, "pseudomorphs" of the original crystal growths. Fig. 6 shows at A the microstructure of the light colored part of the etching pattern and at B the structure of the adjacent dark background. There is obviously no essential difference in the structure and evidently the carbon content is the same. Any original differences in carbon produced by the minor segregation have equalized during the processes of forging and heat treatment. The boundary between the lightly-etched and the darkly-etched parts is not to be found with the microscope and it is evident that the patterns revealed by etching or by sulphur printing do not necessarily correspond to real structural differences but are spectral remains of the original

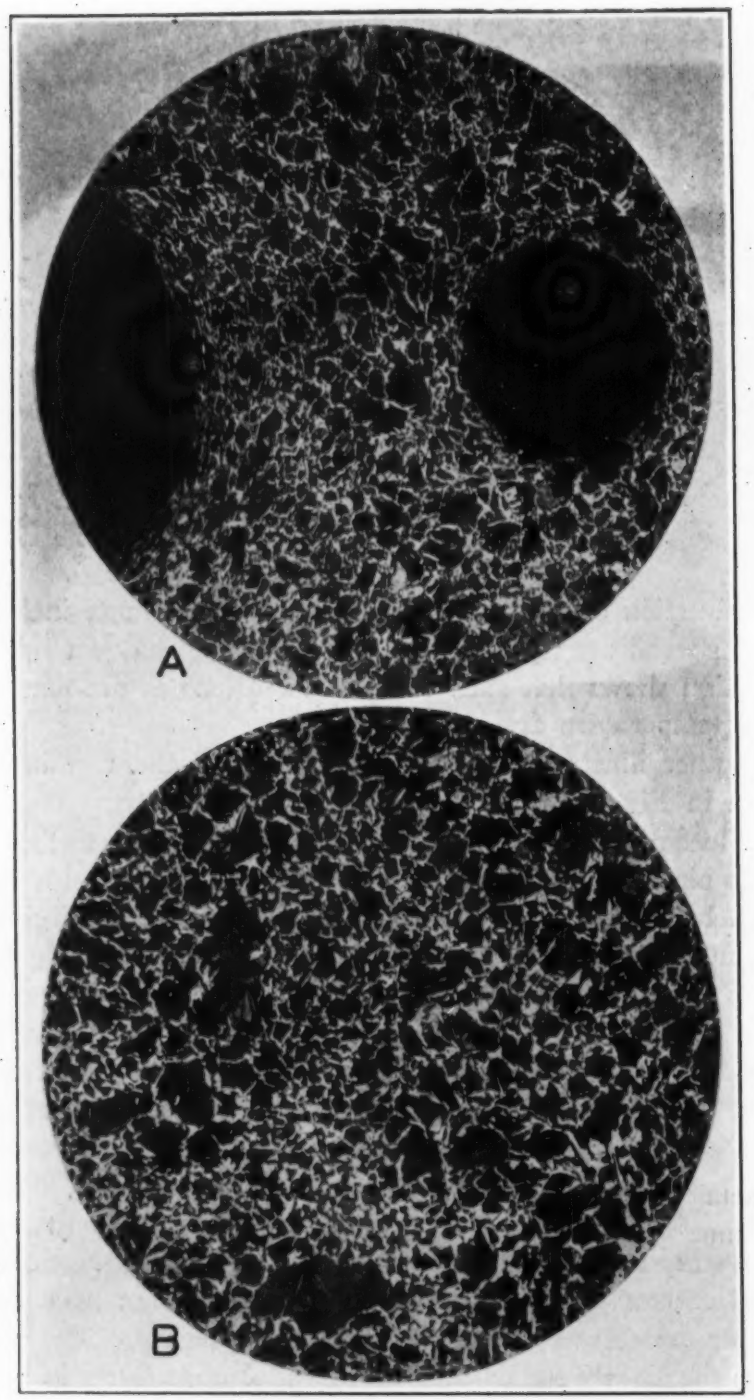


Fig. 6—Photomicrographs of Light and Dark Constituents of Etching Pattern Shown in Fig. 5. A is taken on the Light-Colored Band or Dendrite Marked X in Fig. 5. The Dark Circles are Two Prick-Punch Marks made before Polishing for the Microscope so as to Locate the Band when Polished. B is Taken from the Dark-Etching Body Structure Adjacent to the Light-Colored Band. There is Evidently no Difference in Microstructure. × 100.

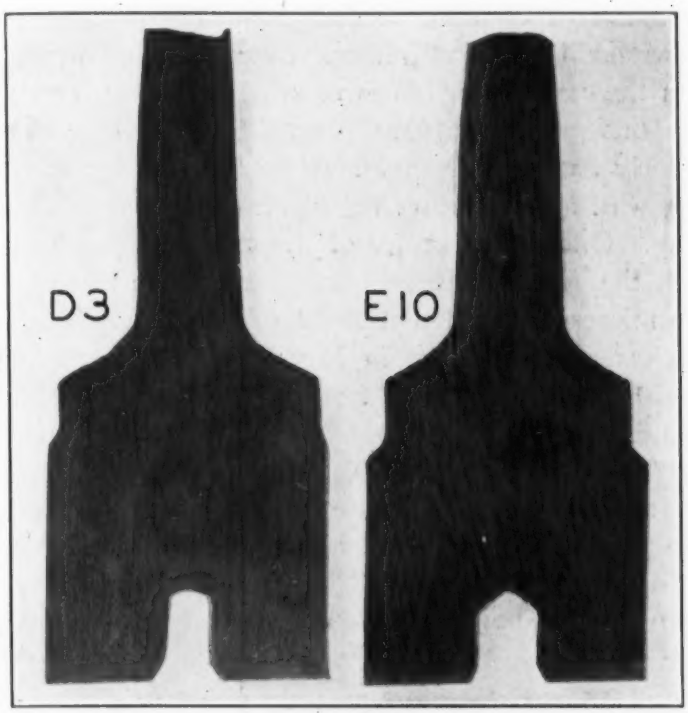


Fig. 7—Photograph of Etched Longitudinal Sections of Broken Tension Specimens from the Same Forging. The Physical Properties of these Specimens are as Follows:—Specimen D3—T. S. 88,500; Y. P. 43,500; Elong. 25%; Red. Area. 40.5%. Specimen E10—T. S. 88,000; Y. P. 47,500; Elong. 26.0%; Red. Area 45.0%.

crystal growths. Further evidence in this direction is offered by Fig. 7 which shows the results of sectioning axially and etching two broken tension test specimens. It appears that there is no relation between the light lines of the etching pattern and the type of fracture.*

While certain parts of the etching pattern are unimportant others have an effect on the character of the forgings. In a longitudinal section the less pure areas of the minor segregation and any plastic nonmetallic inclusions will be drawn out and will etch to show rather deep lines. This structure is responsible for the fiber of the steel. Brearley's[9] studies of fiber shows that the relation between the tensile results in the longitudinal direction and those in the transverse direction measure to a considerable extent the quality of the steel. Poorly made steel containing many nonmetallic inclusions, or steel which has

*Compare H. G. Keshian, "Deep Etch Test for Iron and Steel," TRANSACTIONS, American Society for Steel Treating, Vol. XII, November, 1927, p. 726.

[9]Arthur W. and Harry Brearley, "Ingots and Ingot Moulds," 1918. Longmans-Green & Company, Ltd.

excessive minor segregation because it is cast into large ingots and cooled slowly, will show much fiber. In any forging a certain amount of fiber in the central portion is not to be avoided, and a moderate amount in this position is usually not detrimental to service. This is particularly true of forgings such as axles or crank pins subject to bending which concentrates the maximum stress at the outside of the forging. One other feature of the structure of the steel will be considered, the so-called banded structure which is frequently seen under the microscope in longitudinal sections of carbon steel forgings. An example is shown in Fig. 8A. It is seen to consist of elongated islands or bands of ferrite running longitudinally. The ferrite bands generally enclose elongated particles of manganese sulphide. This banding is of frequent occurrence in annealed carbon steel forgings, but usually the streaks of ferrite are not noticeable in the transverse section. Some railroad specifications for forgings require that the forgings shall be free from banded structure, but in the writer's opinion this is an arbitrary requirement without any practical foundation. Considerable study of forgings with banded structure and comparison with other unbanded forgings has failed to show that the bands are in any way detrimental to the strength of the forgings. Impact tests, transverse and longitudinal tensile tests show no bad effects of banding. An extensive symposium on "bands" and on the related "ghost lines," the larger ferrite segregations which can be seen on the finished surface of certain large forgings, was published in *The Metallurgist,* supplement to *The Engineer,* August, 1926. The general opinion was that the banded structure was not injurious. J. H. Whiteley concludes his article by saying, "Of recent years there has been a tendency to regard the banded formation in structural steels as indicative of inferior quality. There is at present little evidence to justify this view; in fact it is probable that in some ways this structure is beneficial."

If specifications proscribing bands are to be met, the bands may be eliminated by a special high temperature anneal. Figs. 8A and 8B are both from the same forging, a 9-inch locomotive axle, before and after treatment. The bands visible in Fig. 8A have been removed in Fig. 8B. The material has been made to meet specification requirements but there is grave doubt in the author's mind as to whether or not it has really been improved in quality.

Attention so far has been directed mainly to plain carbon steel

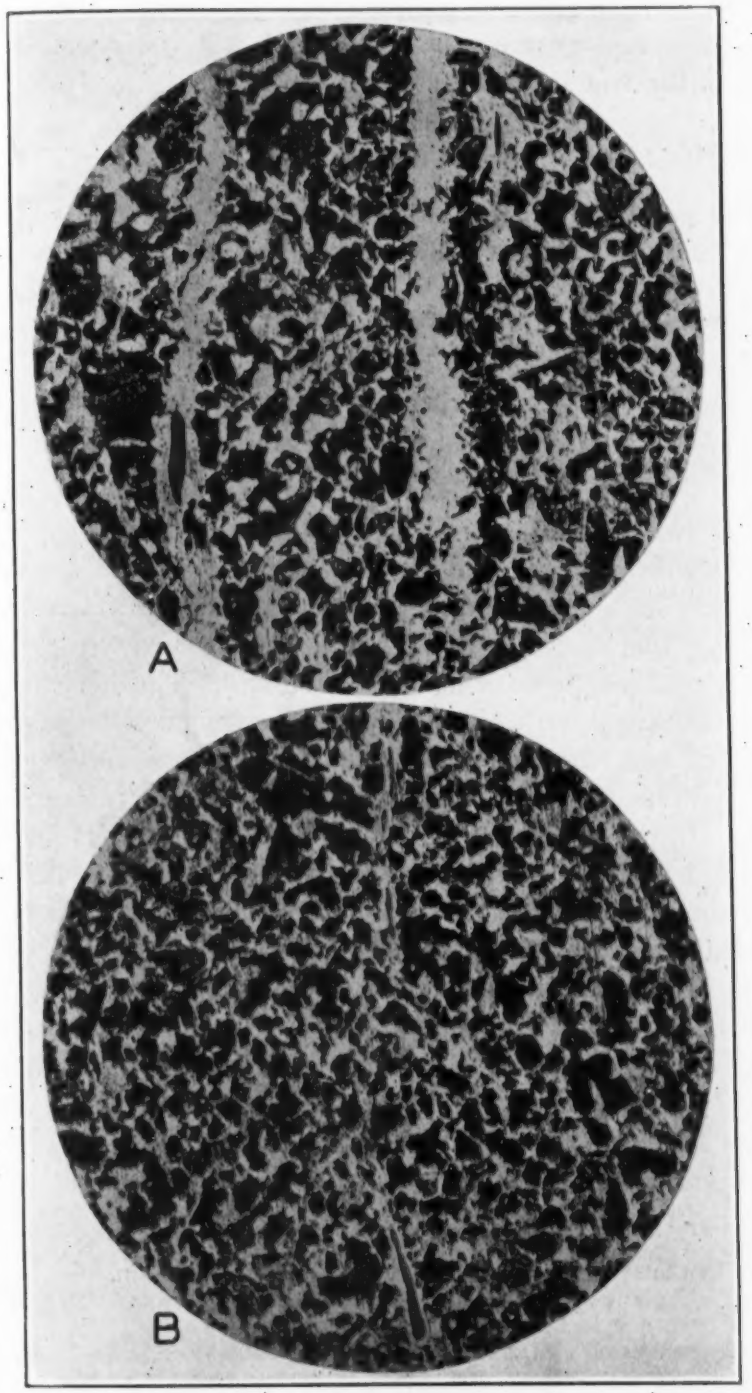


Fig. 8—Photomicrographs Showing Banded Structure. Micrographs from the Same Forging Before and After High Temperature Treatment. A Shows the Original Banded Structure and B the Structure after the Bands have been Removed by Annealing. Both Micrographs are taken in a Longitudinal Plane Parallel to the Axis of the Forging. × 100.

forgings. For the sake of completeness other types of steel used for locomotive forgings must be considered and the question of heat treatment must be dealt with.

Types of Steel

The great majority of locomotive forgings being put into use in this country today are made from one of five types of steels, namely:

1. Plain carbon steel normalized and tempered.
2. Plain carbon steel quenched and tempered.
3. Carbon-vanadium steel normalized and tempered.
4. Chromium-vanadium steel quenched and tempered.
5. Chromium-nickel steel quenched and tempered.

The two last named quenched and tempered alloy steels are not very widely used. They are used mainly under special conditions where high stresses are to be carried or a high factor of safety provided. The tendency at present is to get away from quenched and tempered forgings for locomotive service. The steels being most widely used are those which will give good physical properties when normalized and tempered. "Normalizing" denotes heating to above the critical range and allowing to cool in the air. It is in effect an air quench. It has, though to a lesser degree, the effect of a liquid quench in improving the physical properties of the steel, but does not subject the material to such severe internal stresses. To obtain the best results normalizing should be followed by tempering at a temperature below the critical range.

Based on this treatment modern specifications for carbon steel forgings are being drawn to require tensile properties from 15 to 25 per cent better than were specified ten years ago. Average values for such forgings 10 to 12 inches in diameter from a 0.45 to 0.50 per cent carbon steel with 0.50 to 0.75 per cent manganese are approximately:

Tensile strength	88,000 lbs. per sq. in.
Yield point	54 per cent of tensile strength
Elongation in 2 inches	25 per cent
Reduction of area	42 per cent

As these are average values for a number of forgings, the minimum specified values should be about five per cent lower.

Normalized and tempered carbon-vanadium steel forgings with

carbon 0.35 to 0.45 per cent, manganese 0.75 to 0.90 per cent and vanadium about 0.18 per cent give average values for the tensile properties approximately as follows:

Tensile strength	98,000 lbs. per sq. in.
Yield point	60 per cent of tensile strength
Elongation in 2 inches	24 per cent
Reduction of area	45 per cent

This steel owes its strength and high yield ratio to the manganese content while the vanadium ensures satisfactory grain refinement and consequent ductility. When clean and well made and when properly handled in forging this steel gives excellent results in locomotive forgings. The addition of vanadium to a well made steel will have a beneficial effect on the properties of the steel, but the use of vanadium does not relieve the steel manufacturer of the necessity for using care in the processes of making the steel. Vanadium and other alloys while improving good steels cannot remove the fundamental defects of poorly made steel. In fact since alloy steels are destined to be more highly stressed in the heat treating processes and in service, they require the maximum of care in manufacture to produce good results.

Another normalized and tempered steel that has been coming into prominence recently is a low carbon two per cent nickel with moderately high manganese. This steel has been introduced to secure high ductility. Average values for the tensile properties promise to be approximately:

Tensile strength	83,000 lbs. per sq. in.
Yield point	65 per cent of tensile strength
Elongation in 2 inches	30 per cent
Reduction of area	62 per cent

More extended experience with this steel in service is necessary before its usefulness can be given an exact rating but it promises to be valuable.

Heat Treatment

All of the steels under consideration require some form of heat treatment after having been forged to shape. This is necessary to break up the coarse grain produced by forging, as for example Fig. 9A, and to form the grain structure proper to the composition and the physical properties desired. Examples of the grain structure of various steels after heat treatment are given in Fig. 9.

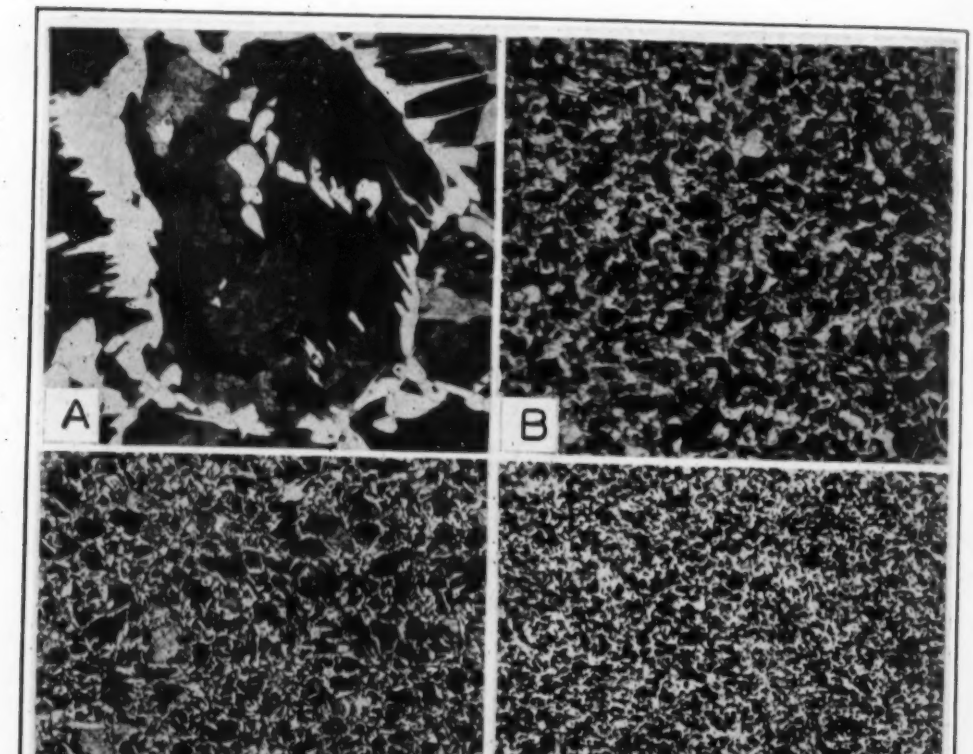
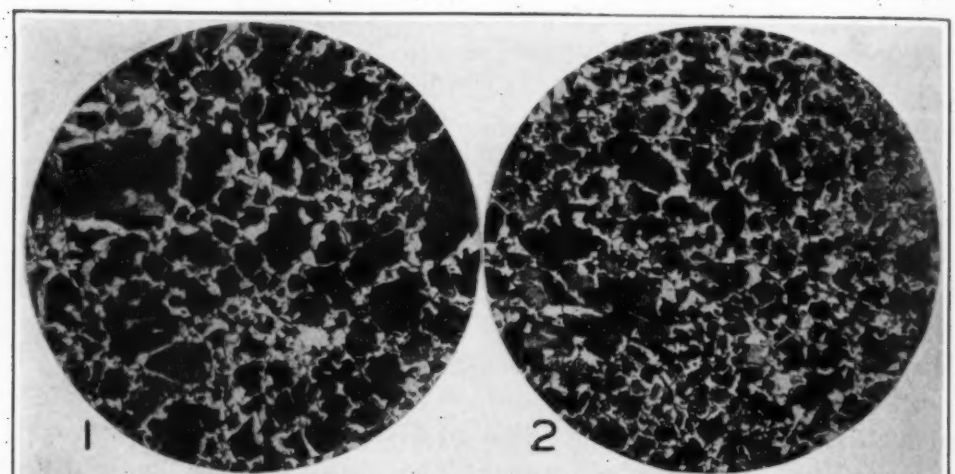


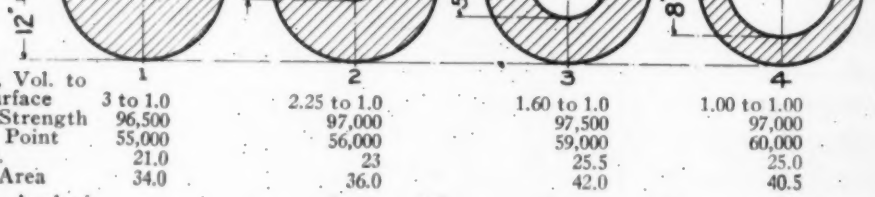
Fig. 9—Photomicrographs Showing Microstructure of Untreated and Treated Steel Forgings. A. Unannealed Carbon Steel. B. Normalized and Tempered Carbon Steel. C. Quenched and Tempered Carbon Steel. D. Normalized and Tempered Carbon-Vanadium Steel. E. Quenched and Tempered Chromium-Vanadium Steel. F. Quenched and Tempered Chromium-Nickel Steel. × 100.

The change in structure produced by heat treatment is a change in microstructure only. The macrostructure revealed by deep etching or sulphur printing remains, as has already been pointed out, unchanged by any heating or cooling.

Details of the metallurgical principles involved in grain refinement by heat treatment are beyond the scope of the present paper. It is sufficient to point out that when steel is heated to a temperature above the so called critical range and held at that temperature for a sufficient time the network structure shown in Fig. 9A disappears. The light areas in Fig. 9A are pure iron, and the dark areas are a mixture of iron and iron combined with carbon. At a temperature above the critical range the carbon goes into solution in the iron and diffuses through the whole mass. The uniformity of the solution and diffusion of the carbon into the iron will depend on the time the steel is held at temperature and the size of the piece. The larger the piece the slower the diffusion. On cooling again through the critical range the carbon comes out of solution and a new network forms. The fineness of the network and the hardness of the steel will depend on the rate at which cooling takes place. Rapid cooling as produced by quenching gives fine grain and maximum hardness. Slower cooling such as in the atmosphere in normalizing gives less grain refinement and less hardness. Tempering or reheating to a temperature below the critical range, will reduce hardness and increase ductility, the effect being greater the greater the temperature.

Heat treatment therefore consists in heating to selected temperatures and cooling under predetermined conditions. Satisfactory heat treatment requires that for quenching or normalizing the forgings shall be uniformly heated to correctly chosen and accurately measured temperatures, that they shall be held at such temperatures an adequate time to permit the desired metallurgical reaction to take place, and shall then be cooled uniformly in the air for normalizing, or in oil or water for quenching. It should be noted that the physical properties obtained by such treatment depend on the speed with which the forgings cool through the critical range. This speed of cooling will be determined by the size of the piece and by the nature of the medium in which it is cooled. Forgings of the same size will cool slowly in air, more rapidly in oil and most rapidly in water. Consequently when physical properties are compared, those of the oil-quenched will be better than, and those of the water-quenched forg-





	1	2	3	4
Ratio, Vol. to Surface	3 to 1.0	2.25 to 1.0	1.60 to 1.0	1.00 to 1.00
Ten. Strength	96,500	97,000	97,500	97,000
Yield Point	55,000	56,000	59,000	60,000
Elong.	21.0	23	25.5	25.0
Red. Area	34.0	36.0	42.0	40.5

Analysis	C	Mn	P	S	Si
	0.54	0.58	0.034	0.040	0.29

Fig. 10—Photomicrographs Showing Effect of Boring on Physical Properties and Microstructure of Normalized Steel Forging. × 100.

ings still better than the properties of the air-cooled forgings. With forgings of different sizes this will not necessarily be true. A very

small piece normalized may cool quicker and therefore give better properties than a large piece quenched in oil. Size as well as cooling medium must be considered in specifying the properties to be obtained. Size also has an effect on the internal stresses set up in cooling. These stresses depend on the temperature gradient, that is, in the difference in temperature between the inside and the outside. This is determined by the rate at which the outside is cooled and the thickness of the section through which the heat must flow. With large sections and rapid cooling the stresses may be so great as to cause rupture. By boring round forgings the section can be very conveniently reduced so as to reduce quenching stresses and to improve physical properties. Boring has the further advantage of reducing the weight with only a slight reduction in strength. In the case of crank pins or axles to be normalized or quenched, a hole having a diameter approximately one-half of the outside diameter is usually good practice. This will reduce the weight by twenty-five per cent and the strength of the section only six and one quarter per cent.

The reduced section permits rapid and uniform penetration of heat and the increased amount of surface in proportion to the volume of metal makes for accelerated cooling. The influence of boring in improving the effect of heat treatment is illustrated in Fig. 10. Two locomotive driving axles 12 inches in diameter forged from the same heat were selected for this experiment and each was cut in half, producing four forgings each 12 inches in diameter and about three feet long. One was left solid, the others bored respectively with holes 3, 5½ and 8 inches in diameter, making the volume of the four forgings 3.00, 2.25, 1.60 and 1.00 cubic inches per square inch of surface. The four pieces were then heated together to a temperature of 1500 degrees Fahr., held 6 hours at this temperature and allowed to cool in the air. The tensile properties and the photomicrographs obtained are shown. As the diameter of the bore is increased there is a general improvement in the microstructure and in physical properties, though this is less marked between the 5½-inch and the 8-inch bores than in the other steps. A 5½-inch bore in a 12-inch axle, besides facilitating heat treatment, reduces the weight about 20 per cent and the strength only about 4.4 per cent. It can be seen that there is considerable advantage in boring large forgings even for normalizing. For quenched forgings the advantage is still greater because the reduced section reduces the internal stresses which may easily become excessive with large solid forgings.

Tensile Properties

Having noted above the average values of the tensile properties which may be counted on in locomotive forgings made from the various types of steel it seems appropriate to discuss briefly the relation between these various tensile properties. This subject has not received the attention that it deserves. It is particularly important when acceptance specifications are to be prepared.

Four tensile properties are measured usually in acceptance tests for steel forgings; the ultimate tensile strength, the yield point, the elongation in 2 inches, and the reduction of area. For any given type of steel and for a given heat treatment these four properties must bear a definite relation to each other. Consider first a plain carbon steel normalized and tempered and take the tensile strength as the basic property. If a number of forgings from various melts of steel, treated in different lots, are tested, it will be found that in spite of all reasonable care to obtain uniformity the values for the tensile strength will vary through a range equal to about nine or ten per cent of the mean value. Thus, if a minimum tensile strength of 85,000 pounds per square inch is specified, the average value will be about 89,000 pounds per square inch with a range between 85,000 and 93,000 pounds per square inch. The variation will be due in part to variations in composition of the various melts, and in part to variations in heat treatment. Such variations in tensile strength occur not only between different forgings, but also between different parts of the same forging. In a recent study of the properties of forgings thirty-two tensile tests were taken from a forging 10½ inches in diameter and about fifty inches long. All test specimens were taken from the standard position, that is one-half way between the center and the outside. Twenty-five of the thirty-two tests gave tensile strength between 87,500 and 88,700 pounds per square inch, indicating a high degree of uniformity in the forging. The highest and lowest values found for the tensile strength were 86,300 and 91,500 pounds per square inch, respectively. The yield point stands in close relationship to the tensile strength, but before discussing values it is necessary to decide on how they are to be measured. For the present purpose yield point is taken to be the load per square inch at which with a uniform test machine speed there is a definite drop of the beam of the machine. The value found for the yield point for any forging will depend on the speed at which the test

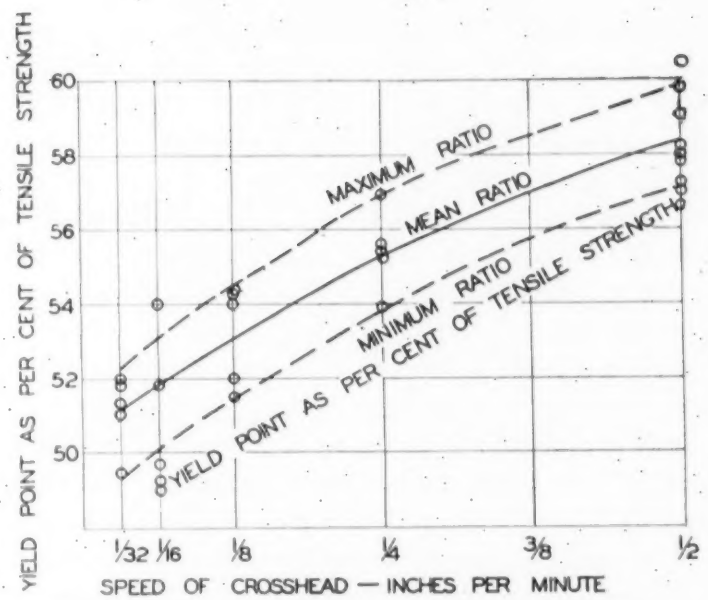


Fig. 11—Curves Showing Effect of Speed of Testing on Yield Point.

machine is run. Fig. 11 shows the yield point values found for a number of specimens from one forging when tested with different test machine speeds. The speeds given are those of the crosshead of the machine when running without a specimen. The thirty tests represented in Fig. 11 were all made with specimens taken from the forging referred to above. This was made of acid open-hearth steel having the following composition:

	Per Cent
Carbon	0.51
Manganese	0.63
Silicon	0.26
Phosphorus	0.030
Sulphur	0.036

With a test machine speed of one-eighth inch per minute the yield point values vary from 50.3 to 54.0 per cent of the tensile strength. These are all tests from a single forging. If a number of forgings are compared the range will be somewhat wider, say from 50 to 55 per cent of the tensile strength.

The elongation and reduction of area also depend on the tensile strength but by an inverse ratio. Fig. 12 shows the values of elongation and tensile strength plotted for a number of tests. The average values are well represented by the curve, tensile strength times

elongation equals 2,230,000, while the minimum values are not very different from the curve, tensile strength times elongation equals 2,230,000. It is evidently proper in drawing specifications to take into account this natural tendency for the elongation to increase as the tensile strength goes down. For example if a specification is to be drawn for normalized and tempered carbon steel with a minimum tensile strength of 85,000 pounds per square inch, it is to be expected, as shown above, that actual tensile strength values will range from 85,000 up to about 93,000 pounds per square inch. Then a decision should be made as to the minimum elongation which will be accepted with the maximum tensile strength. For example for forgings not over nine inches in diameter it would be proper to specify that with a tensile strength of 93,000 pounds per square inch the elongation in two inches should not be less than 23.0 per cent. Then for lower values of the tensile strength proportionately higher values of the elongation should be required. The following table shows the minimum values for the elongation which, on this basis, would be acceptable for each value of the tensile strength.

Value of Tensile Strength in Pounds Per Square Inch	Minimum Acceptable Value of Elongation Per Cent
85,000	25.0
86,000	24.8
87,000	24.5
88,000	24.2
89,000	24.0
90,000	23.7
91,000	23.4
92,000	23.2
93,000	23.0
over 93,000	23.0

This relation between elongation and tensile strength can be obtained by specifying that the quality factor, or tensile strength multiplied by elongation, shall not be less than 2,130,000. The use of this quality factor to provide a sliding scale for the elongation required is preferable to merely specifying a flat figure for the minimum elongation to be acceptable for all tensile strengths. If for example a flat minimum elongation of 23.0 per cent were specified, all forgings with an elongation of 23.0 per cent would be acceptable, whether the value of the tensile strength was 93,000 or only 85,000 pounds per square inch. For the former the quality factor, tensile strength multiplied by elongation, has the value 2,130,000 while for

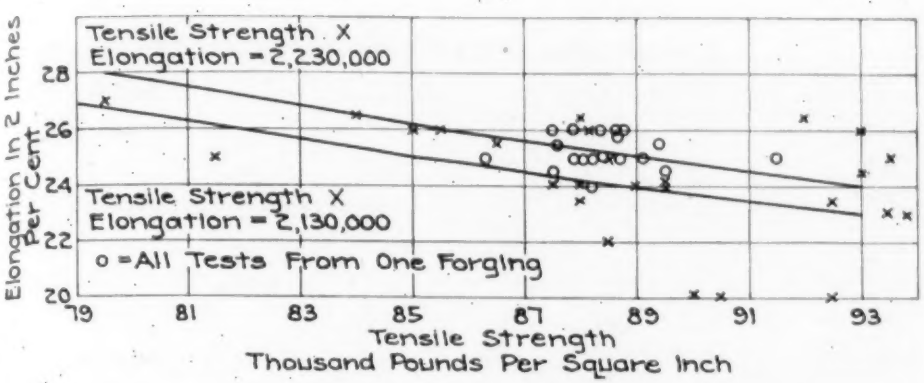


Fig. 12—Curves Showing Relation Between Elongation and Tensile Strength.

the latter its value drops to 1,960,000. There is no advantage to the manufacturer in allowing forgings of this grade to have lower quality factor values at the lower tensile strengths, and it is therefore desirable to give the user the protection afforded by specifying that the elongation shall be determined from a sliding scale with a constant quality factor. In the case under consideration this would be done by specifying that the elongation in per cent shall not be less than 2,130,000 divided by the value of the tensile strength and that where the tensile strength is more than 93,000 pounds per square inch the elongation shall not be less than 23.0 per cent.

If a number of tests of similar forgings are compared it will be found that the conditions indicated in Fig. 12 are representative, that is that the average value of the elongation will be about five per cent higher than the minimum specified value. Fig. 12 also shows that if a number of tests are taken from a single forging, the values of the elongation may vary from 23.5 to 26.0 per cent and the values of the tensile strength from 86,300 to 91,500 pounds per square inch. The average value of the elongation is 24.2 per cent and the average value of the tensile strength is 88,300 pounds per square inch. The relation between these two average values as plotted in Fig. 12 falls on the curve corresponding to the average quality factor for the other forgings, but in the individual tests from the single forging there is no tendency for the elongation to vary inversely with the tensile strength.

The reduction of area stands also in inverse ratio to the tensile strength, and all that has been said regarding the elongation applies equally to the reduction of area. For the size and type of forgings considered above a proper minimum value for the quality factor,

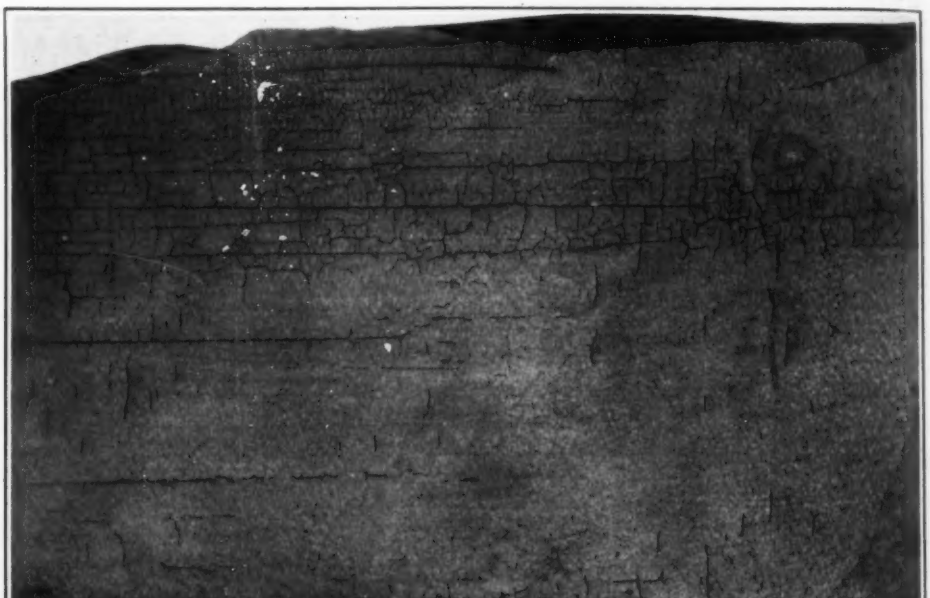


Fig. 13—Photograph of Section of Locomotive Driving Journal Showing Thermal Cracks Produced as a Result of Poor Lubrication.

tensile strength multiplied by reduction of area, would be 3,400,000.

For quenched and tempered carbon steel forgings the relations between the physical properties are generally the same as those just examined for the normalized and tempered carbon steels, however, the numerical values are different. One difference in measurement must be noted. Instead of taking the yield point by the drop of the beam it is usual for quenched and tempered forgings to use an extensometer and to note the load at which there is a sudden acceleration of the extensometer needle. In the specifications this is called the "elastic limit." In fact it has a value above that of the true proportional limit but below that of the yield point by drop of beam. This method was introduced about 15 years ago, apparently in the belief that it would give a more exact value than the determination of the yield point by drop of beam. Recent study of the question indicates that this belief is not well founded. Particularly with normalized and tempered material the values found for the yield point by the drop of the beam, when compared with values given by the extensometer are found to be less erratic for a given lot of material, and in addition have the advantage of being more simply and

definitely observed and are less dependent on the personal equation of the observer.

For the alloy steels the conditions as to yield point are the same as for the plain carbon steels, but the inverse ratio between tensile strength and the ductility factors, elongation and reduction of area is not so well marked. This applies to both the normalized and the quenched steels and therefore in all of the alloy steel specifications it is usual to specify flat figures for elongation and reduction of area instead of using a sliding scale.

Conclusion

In choosing any of the special steels in an attempt to correct a definite type of trouble, as for example axle failures occurring in the journal, all phases of the problem must be considered. If the failed axles show thermal cracks, such as are illustrated in Fig. 13, it is evident that the lubrication has been faulty and it will be good engineering to correct this service condition by mechanical methods, rather than to attempt to find some special steel which will operate successfully under unnecessarily difficult conditions.

At the same time it must be recognized that locomotive forgings are not designed to be wrapped in cotton wool. Rough service and occasional abuse must be encountered. It is to meet such conditions that the special normalized and tempered steels are being developed. At the present time there is some difference of opinion as to whether it is better to use a steel with high tensile strength or with high ductility. As has been pointed out both types of steel are being tried. Time will bring further information. The problems of producing and handling forgings so as to give constantly better and more reliable results in locomotive service concern both metallurgical and mechanical engineers, and it is only by the fullest cooperation between producers and users that progress can be made.

DISCUSSION

Written Discussion: By Wm. M. Barr, Union Pacific System, Omaha, Nebraska.

In his paper on Locomotive Forgings, Mr. Fry has covered the entire subject so thoroughly and at the same time so clearly that there is little need for discussion.

There are some points that deserve emphasis and some may be interested in the observations of a consumer who has tried to co-operate with the manufacturers in the study of a problem that has become increasingly more difficult, due to the demands of operating railway executives.

Mr. Fry calls attention to increased loads placed upon the forgings of the modern locomotive. These can be calculated with a considerable degree of accuracy and can be provided for by the designer. He does not mention what one of my co-workers has aptly termed "accidental loads." These are loads which the forging may be called upon to bear as the result of sudden shock induced by the breaking of a companion part, or the improper functioning of some other part of the machine. With the increase in the size of the locomotive, increased loading and greater speed these accidental loads become enormous. This was well illustrated by the pulling apart of a side rod on a large engine as a result of the failure of a companion part. The rod broke as a result of a direct pull, the fracture looking like that of a test specimen after a tension test. While forgings cannot be made that will meet all such conditions it serves to emphasize the need for the highest quality attainable to meet present day service. Nor must we forget that the finest forging made can be ruined in the machine shop either by careless finishing or by lack of understanding on the part of the machinist of the properties of the metal with which he is working. The heat treater can do much by acquainting the machinist with the properties of the forgings which he sends to the machine shop for finishing.

The author has pointed out the care required in the proper making of steel. It has long been customary to buy forging billets to a simple chemical specification without much regard to the physical structure. It is of the utmost importance that blooms like that shown in Fig. 1, be rejected. One of the most profitable things the consumer can do is to pay the steel maker a premium for careful workmanship and for heavy cropping of ingots to assure freedom in the forgings from pipes, gas pockets, and undue segregation of the chemical constituents. A single unsound forging from a heat of steel otherwise perfect, constitutes the weak link in the chain, the failure of which may result in disaster.

For the making of high quality forgings the author indicates a preference for one method of manufacture, but as he states in connection with the use of the electric furnace, there is no process that can overcome lack of skill or prevent the production of poor forgings by careless manufacture. We have experienced poor forgings made by every known method. At the same time it may be said that equally good results have been obtained with forgings from steel made by the acid open-hearth, basic open-hearth, and electric furnace. Similarly it may be said as a result of examining a large number of blooms and forgings that excellent forgings have been made from rolled, pressed and forged blooms. I would select my steel maker as I would my surgeon, not so much for the methods he employs as for his known skill and integrity.

Heat treating is a science and with the same steel the same result can be repeated any number of times. To do this the operator must know definitely the temperatures and time required, and must have furnaces in which uniform conditions can be produced. No longer does the

heat treater, however skilled he may be, depend on his eye and hand for control of the process, but accurately calibrated instruments guide him at each step. This is more important today than ever before, because of the constantly increasing number of formulas used in alloy steels, each of which requires some variation in the heat treatment. Great progress has been made in recent years in the improvement of the properties of forgings by correct heat treatment. This is especially noticeable in improved ductility without undue sacrifice of other tensile properties. As the yield point is the controlling factor to be considered by the designer, this must be sufficiently high to meet the requirements of the service. From a study of failed forgings, it seems that, with adequate yield point as high ductility should be obtained as is consistent with good wearing qualities.

The dominant note in Mr. Fry's admirable paper is care in all stages of production, and he is to be congratulated on the thorough and concise manner in which he has presented this subject.

Written Discussion: By J. J. Laudig, Delaware, Lackawanna and Western R. R., Scranton, Pa.

The paper presented by Mr. Fry shows that he has made a thorough study and had control over all the conditions in the manufacture of locomotive forgings, starting from the stock pile through the open-hearth, forge shop and machine shop,—an opportunity that is denied many of us. His observations, therefore, are more complete than those who usually specify the manufacture of the steel and produce and treat forgings therefrom, although sometimes the latter group have an advantage in observing the results of material in service.

I am glad that Mr. Fry drew attention to the investigation made on the reduction of ingot to forging. The group of men that conducted this investigation cleared up the misunderstanding caused by the arbitrary ruling in most specifications of a reduction of four to one.

His statements regarding microstructure, especially banding, are open to question inasmuch as it is generally conceded that banding is usually accompanied by excessive segregation. I have seen many cases of banding which could not have been broken up by any type of heat treatment.

The author mentions six types of steel for locomotive forgings, probably the greatest quantity being in types 1 and 3. He makes no mention of the method of tempering after normalizing. I think that this is a very important point: whether the tempering is done by cooling below the critical range in the furnace rather than drawing out into the air. Certainly it must be conceded that tempering in the furnace to remove the normalizing strain places the steel more nearly at rest and free from residual strain. I think that the subject of residual strains in heavy forgings and their effect upon service is worthy of more consideration.

Low carbon 2½ per cent nickel steel has given some remarkable physical properties on test in both heavy and light forgings; and being an earnest advocate of ductility rather than high yield points, I am following the service of these forgings with much interest.

Mr. Fry has introduced some very interesting correlations between the tensile strength and elongation and between the yield point and speed of test. Unquestionably the speed of testing as applied to modern locomotive forgings will require more attention than heretofore.

Mr. Fry's paper has gone into detail in all phases of the production of forgings but I do not think he has stressed sufficiently the importance of proper machining.

Undoubtedly, with large quantities of steel receiving a new type of treatment, such as normalizing and tempering, rather than common annealing, much greater care must be given the tests on the forgings in order to get a true measure of the superior results obtained. Locomotive forgings receive very hard usage, which has called for a better quality of material. And with the entrance of alloy steels into this field there has come a greater appreciation of care in their forging, machining and maintenance. No doubt the fine records they have already made have been due as much to the appreciation and care of the finished product as to the use of the superior quality of material.

Written Discussion: By E. J. Edwards, engineer of tests, American Locomotive Co., Schenectady, N. Y.

We are indebted to Mr. Fry for his timely contribution on this very important subject. However, it has occurred to me that there are other important features in connection with the subject which should be given our serious consideration. The photograph of the undesirable forging bloom is a condition which should be avoided and represents nothing but poor steel making. The manufacturers of locomotive forgings, as well as the manufacturers of the bloom, should take such precautions as are necessary to make certain that such a bloom does not even enter the forging plant.

In the inspection of locomotive blooms, I have found that the mere making of a chemical determination is not sufficient to protect the consumer against unsound steel. Tests are available which will eliminate the undesirable material. Chemical determinations made from center drillings as well as from the usual drillings taken at a point one-half way between the center and the edge, will protect the consumer in a general manner. However, it has been my experience that the macro etching is the best test which we have available to furnish information as to the soundness of the steel. This test has been followed by me for several years in the inspection of all alloy steel blooms and has in a large measure eliminated the undesirable steel. The fact of the matter is that it has been several years since I have seen forging blooms in our plant which were of an unsound nature.

In Mr. Fry's discussion he brings out that steel made by the acid process is more free from oxides, inclusions, etc. This as we know is a matter of considerable controversy. I have seen poor steel made by all of the three recognized methods: acid, basic and electric furnace material.

In the production of quality forgings we have found that equally as

good success can be obtained from a billet which has been rolled. Further, quality forgings are produced by either hammering or pressing. When it is found necessary to allow the ingot to become cold before forging or rolling, great care must be exercised in heating said ingot, especially at the lower temperature and when first applying the heat. This, in order to avoid the possibility of thermal ruptures.

In the manufacture of high quality blooms today, the manufacturers have found that it is desirable to cool said blooms very slowly, and for this purpose, cooling pits have been installed. Because of the exacting requirements which have recently been adopted by the American Society for Testing Materials and the American Railway Association, it has become absolutely necessary that correct forging temperatures be insured. It is our practice to have the forging furnaces at all times under pyrometrical control. This insures that the steel has been heated slowly and to a proper temperature with ample time to make certain that the heat has penetrated uniformly through the mass. Penetration being equally as important as is the proper temperature.

Mr. Fry in referring to the composition of straight carbon steel makes reference to the fact that the manganese content should range from 0.55 to 0.70 per cent. The more recent specifications written have increased the manganese content materially; and it is a question in my mind as to the advisability of increasing this manganese content, especially in axle forgings.

In passing, I would add also that the American Railway Association have recently incorporated rejection limits for straight carbon steel where the residual alloy chromium is in excess of 0.15 per cent and where the nickel content is in excess of 0.25 per cent. These additional chemical rejection requirements will no doubt work a hardship on the producer, due to the quality of the scrap which is available today. Further, I am of the opinion that such a small amount of such elements will have no influence whatever on the life of the steel, but as a matter of fact will assist in producing high physical properties.

My experience has been that quenching in a solution of the larger masses in both the alloys and the straight carbon steel should be avoided, because of the fact that thermal ruptures frequently develop in such materials. To avoid this drastic treatment, the railroads have recently adopted the use of a normalized and annealed practice—a procedure which I have followed for many years in the production of real quality material. The normalized forging is, of course, not subjected to the drastic treatment that a forging which has been immersed in a solution has been subjected to, and for this reason is to be desired.

However, because of the very high physical properties which have been obtained in the normalized and annealed products, it seems that the railroad companies are incorporating rejection requirements which will result in the loss of forgings which should give the best of service. As a matter of information to the members present, it may not be generally known that the latest revised requirements for locomotive forgings are

much more severe than are specified for forgings of equal sections used in other types of construction.

To my mind, the metallurgist has not received the co-operation which he should have received in the proper designing of forgings, and further in the maintenance of said forgings in service. It has been several years since I have seen a forging which had failed because of the quality of the steel. It is more difficult to convince the mechanical man and the designer that failures are due to causes other than materials. It behooves the metallurgist therefore to stress this important feature with both the designing engineer and with the railroads.

Today, we are confronted with an epidemic of axle failures. In fact, too many such failures are reported. In nearly all cases, however, when a complete investigation is made, it is usually found that said failures are due to one of two causes: improper fillets, or lack of lubrication. The question of better fillets and the elimination of indentations, scratches, etc., has been stressed in the past by the speaker. Further, a better or a more certain means of lubricating our locomotive journals must be found. Unfortunately, our present system of lubrication is wrong, because of the fact that we must develop heat before the lubricant begins to function. Frankly, I am of the opinion that it will be impossible to produce steel for a locomotive journal which will give satisfaction until we are sure of a better means of lubrication.

Mr. Fry in his discussion has made reference to the use of alloy steels in locomotive construction. I have had a long experience in the production of such forgings and have found that Mr. Fry's statement as regards the results obtained with carbon-vanadium steel must be qualified somewhat. Certainly in a straight carbon steel, without the addition of vanadium, we could not obtain the high yield point and the high ductility which are obtained with normalized carbon-vanadium steel. In the use of the low carbon-nickel steel referred to by Mr. Fry, I have again had considerable experience and have found that where ductility is desired, this steel seems to be promising.

In conclusion, I am of the opinion that the railroads of the country today are working in the wrong direction in that the tendency for the higher strength steels is a mistake. For after all, due to the tremendous vibration, impact and the many other stresses which are developed in service, that which is more important in my opinion is a steel of high ductility, be it carbon or alloy and further, that unnecessarily high strength should be avoided. With proper lubrication, and greater care being exercised in the maintenance of locomotive forgings, I am certain that failures could be materially reduced, as the forging manufacturers as a whole, are today producing results on the larger masses found on the locomotive which are the equal to that obtained on the smaller sections ordinarly used in the automobile industry.

Written Discussion: By J. H. Higgins, Camden Forge Company, Camden, N. J.

Mr. Fry's paper on "Locomotive Forgings" is a contribution which

should command the interest of the manufacturer and consumer alike. The author is to be congratulated on the very thorough manner in which he covered every phase of this important subject.

The demands on the manufacturer for better forgings are increasing daily and it is obvious that every care must be used in the selection and working of steel in order to meet these demands. While it is generally understood that steel made by the acid process is more free from inclusions than the basic process, it would be well to determine how many forging failures are caused from inclusions and what amount of inclusions are detrimental to forgings. These major questions must be considered when we discuss the superiority of one steel over another.

Investigations conducted on failed forgings rarely disclose failures due to open pipes or segregation. These failures are prevented in present day practice by etching a section taken from the top of each billet or ingot. The use of basic steel for locomotive forgings is approved and accepted by mechanical engineers with but few exceptions. Laboratory as well as service tests have proven it to be comparable to acid steel and entirely satisfactory so far as cleanliness and strength is concerned.

In the writer's opinion, the production of good forgings is not a question of acid or basic steel, but the selection of fundamentally sound steel and the manner in which such steel is heated, forged and treated and how much care is used in finish machining and the proper lubrication after being placed in service. Unless care is used in all the above factors, forgings will fail regardless of what kind of steel is used in their manufacture.

Written Discussion: By E. A. Kuhn, Nickel Plate R.R., Cleveland.

In discussing this paper, I am going to hold my remarks to the last paragraph of Mr. Fry's address, wherein he mentions that the problem of producing and handling forgings is one requiring the co-operation between both metallurgical and mechanical engineers.

It would be futile for me to attempt to bring out anything further in regard to manufacture of forgings. However, I can tell you briefly some of our problems in regard to handling of the finished forging.

In designing such parts to be made by the forging process, careful study must be made, not only taking into consideration the stresses to which the parts will be subjected, but also the use to which they will be put. I refer chiefly here to repair work and facilities for making same. Some shops are not in a position to properly heat treat the various alloy steels after working same and on any parts that are subject to repairs, consideration should be given to furnishing a steel that can be handled by the shops. If necessary to use an alloy steel, strict instructions should be issued to prevent the working of these parts by men not properly tooled for it. I know of one case where a driving rod on a locomotive was heated locally to straighten and after being returned to service broke just ahead of the heated zone, causing approximately $3000 damage. It developed that this rod was straightened satisfactorily, but was not normalized afterwards.

Stresses on locomotive parts have increased to such an extent that in many cases we must use alloy steel. On this account facilities should be provided for proper maintenance. Where these facilities are not available in our own shops, arrangements should be made with outside concerns for the handling of this work.

Another point I would like to lay stress on is the use of autogenous welding. I recognize the fact that it would be practically impossible to railroad today without welding. However, there are certain parts on which autogenous welding must be prohibited. The intense heat occasioned on the base metal by the fusion heat of the welding process causes a hard structure readily fracturing. I have observed numerous failures that were chargeable directly to the welding process. In most cases there are other methods that can be used to reclaim parts other than welding, and where it is not possible to reclaim, it would be a saving proposition to scrap it rather than subject yourself to the possible high damage losses caused by the failure of such parts.

In studying failures of forged parts, it is necessary, as Mr. Fry brings out, to give careful consideration to the nature of the failure in order to determine whether the trouble can be overcome by mechanical methods, or whether some special steel should be used. At the present time we have such a problem in front of us and after experimenting with both low ductility high tensile strength steel and a steel having a high ductility, very little difference was found in the performance of the two. By investigating the actual application of this part, improvements were made in the method of using the same, which has so far indicated that it will overcome the trouble.

There are a number of parts on locomotives on which it is necessary to apply filets in order to compensate for steps in the finished forgings. Great care should be taken in the machining of these fillets as failures have occurred at this point due to what would be considered minute tool marks. This has been partially overcome by the use of a forming tool carrying the same radius as the fillet.

Few men are able to satisfactorily analyze any failure by themselves and we have found the best policy is to conduct our preliminary examination with the assistance of local consulting engineers, who furnish us with description of the grain structure of the failed part. We then put these problems up to the metallurgical engineers connected with the forging companies that furnish our material. In this way, we have been able to develop valuable information as to processes that have been in effect for some time, but that are not satisfactory for the higher stressed material that we are now using.

It is sometimes difficult to convince the shop men that certain processes are not desirable as they have used them for a number of years without trouble, but we find them ready to go along with us when we can put our story to them in a way that they understand.

Written Discussion: By Charles McKnight, chief of alloy steel development, International Nickel Co., New York, N. Y.

Mr. Fry's paper, embodying as it does the fruits of his long experience, is of great interest. So little matter controversial in nature has been included that discussion would seem necessarily to be along the line of amplification.

Mr. Fry briefly mentions the use of normalized, low carbon-nickel steel. The use of this steel has been greatly extended recently and now sufficient experience has been obtained with it to predict accurately its performance. In the development of locomotive parts the tendency has been to higher and higher tensile strengths. Taking locomotive driving axles for example, wrought iron was originally used with an ultimate tensile strength of 45,000 pounds per square inch. This was later replaced by carbon steel with an ultimate tensile strength of 75,000 pounds per square inch and carbon steel, in turn, has quite generally given way to alloy steel with a tensile strength of 90,000 pounds per square inch or higher. It has perhaps been natural to reason that if failures occur with one material a stronger material will obviate the difficulty and it has been this reasoning which has induced the railroads to use steels of higher and higher strengths with little or no advantage being taken of the strength in order to reduce the size of the sections used.

The logic of this reasoning can be questioned and it would seem that too much attention has been paid to strength and not enough to the so-called toughness factors—reduction of area, elongation, impact and fatigue values. The practical limit of strength, however, has now been reached for normalized forgings and, no matter what alloy is used, it is not possible greatly to increase the strength over that now being reached. In spite of high strengths now in vogue, breakages are still occurring. By the use of nickel, it is possible to obtain in a normalized forging as high strength as with any other steel but, recognizing the existing dilemma, recourse has been had to the other extreme and a comparatively low carbon-nickel steel is now being used as a material for the stressed forgings on locomotives with satisfactory results. The physical characteristics of such a steel are in general in accord with the figures given by Mr. Fry. The average results on a large number of locomotive forgings, such as main axles, main rods and side rods, are as follows,—

Ultimate Tensile Strength	83,568 lbs. per sq. in.
Yield Point	60,407 lbs. per sq. in. (72.3%)
Elongation	31 per cent
Reduction of Area	63.7 per cent
Izod Impact Value	70-80 ft. lbs.

It is evident that with a slight reduction in strength the toughness factors have been increased 25 to 30 per cent, and it is interesting to note that the impact value for this low carbon-nickel steel is 70 to 80 foot-pounds Izod which is about double that usually obtained for normalized alloy steel forgings of higher carbon content.

The average analysis of these forgings was,—

	Per cent
Carbon	0.225
Manganese	0.88
Silicon	0.23
Nickel	2.61

When this steel was originally brought to the attention of the railroads, a nickel content of 2.50 per cent was recommended in order to keep the cost of the steel in a range which would be economically attractive. In some cases, the railroads themselves have raised this nickel content and the range now is customarily between 2.50 and 3.50 per cent. This has been done in the face of increased cost in order to obtain even higher physical qualities.

At the end of his paper, Mr. Fry deals briefly with the subject of thermal cracking of journals. It is not fair to expect any steel to stand up under some of the conditions of faulty lubrication met with in service. If the main driving axle of a locomotive is permitted to run without adequate lubrication until it heats up and is then cooled by throwing water on it, as is often the case, it will be an exceptional steel which will not show some signs of abuse. However, low carbon steels—and particularly the low carbon-nickel steels—are more resistant to this abuse than the higher carbon steels, thus bringing an added advantage to the use of the tough steels.

Written Discussion: By H. A. F. Campbell, Baldwin Locomotive Works, Philadelphia.

Mr. Fry, in his usual clear and readable way, has brought out for us the high spots in the manufacture of forgings for say a connecting rod or a driving axle. No one is better able to write on this matter than Mr. Fry, and he has given us a most excellent paper.

The writer would like to touch on a point, however. Our specifications for the physical qualities for locomotive forgings lay great stress on the tensile strength, the yield point, the elongation in 2 inches, and the reduction in area. If these meet certain fixed requirements, then the forging is said to be acceptable. But is the same class of steel the most suitable for a side rod as for a piston rod? There is considerable evidence that certain locomotive parts have failed in compression, that is, along a shearing surface, and not in tension. A nickel steel may be very fine in tension, but is it any better, if as good, as a carbon steel in compression, that is, in shear?

Also let it be remembered that because a piece of steel meets the present physical requirements, which are static tests, it does not follow that it will hold up well under repeated and reversed stresses, or under heavy shock loads. There is considerable evidence that for example a wrist pin of a very close grained carbon steel with high ultimate strength and only medium elongation and reduction of area is superior, for this particular part, than any alloy steel.

One of the helps to obtain this very close grain is to use hollow-bored parts and to bore a real hole. It is really the only way to obtain the very necessary heat treatment results.

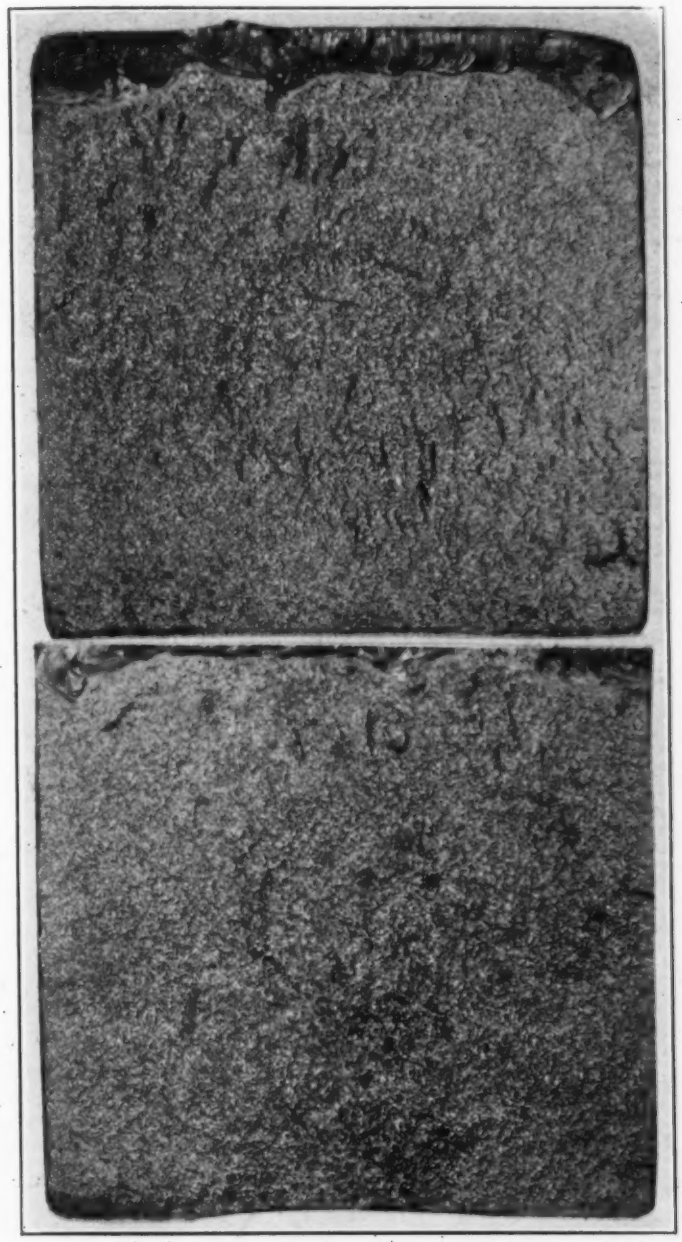


Fig. 1—Showing Defects in Fracture When Billets were Broken for Inspection.

Written Discussion: By B. F. Shepherd, metallurgist, Ingersoll-Rand Co., Phillipsburg, N. J.

The attention which Mr. Fry gives to the special selection of steel for forging cannot be too greatly emphasized, if the highest grade product is to be produced. In the manufacture of locomotive crank shafts, certain firms follow the practice of inspecting by breaking each billet into

Fig. 2—Showing Face of Slab Etched to Show the Defect is Not Encountered with the Method of Fracturing. (Above) Slab was Taken ¾ Inches Behind Fracture. (Below) Slab was Taken 2 Inches Behind Fracture.

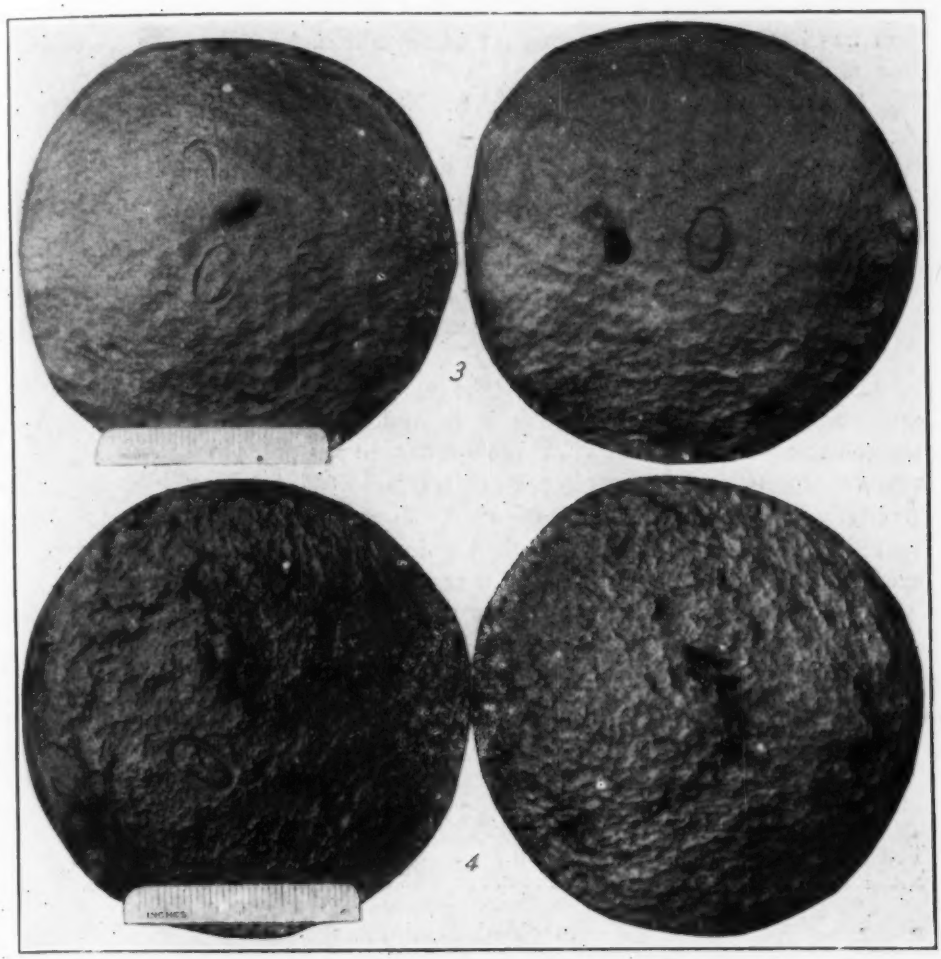


Fig. 3—Showing Bursts on Ends of Forgings Caused by "Weak Center." Manufacturer B.
Fig. 4—Showing Similar Bursts. Manufacturer P.

forging lengths and inspecting the fracture. While major defects, secondary piping, etc., have often been encountered, the writer wishes to call attention to a defect which is seldom described.

This has been called "center weakness," for want of a better name and very aptly describes the condition. The fractures reveal a center discontinuity, which is usually quite small, as shown in photograph Fig. 1. This defect is in no way connected with the strains incident to fracturing the material for inspection as can be seen from photograph Fig. 2. This shows etched sections taken at ¾ to 2 inches from the fracture, and upon etching shows the discontinuity seen in the fracture. This difficulty is also present to a degree where it will not show on the fracture or upon etching, but will show on severe forging operations. The end of the forging will open up in the manner shown in Figs. 3 and 4. When this end is removed and etched, the cross section shows no trace of

the weakness which caused the forging to open up. This type of defect has been found in the product of several makers, in both simple carbon and alloy steels.

Written Discussion: By G. L. Norris, Vanadium Corporation of America, New York City.

I want to congratulate Mr. Fry upon the clear and thorough manner in which he has covered the subject of his paper. There is, however, one statement with which I do not agree. That is his statement in regard to vanadium steel. He states that

> "This steel owes its strength and high yield ratio to the manganese content while the vanadium ensures satisfactory grain refinement and consequent ductility."

It is a well established fact that vanadium increases the strength of any composition steel to which it is added, and very materially raises the elastic or yield ratio. Undoubtedly increasing the percentages of manganese in carbon forging steels is reflected by increases in tensile strength, although a study of many locomotive forging tests shows scarcely any difference in the yield point and tensile strength by an increase of 0.15 to 0.25 per cent of manganese.

The following ranges of tensile properties are typical for locomotive forgings of carbon steel and carbon-vanadium steel of the same composition range, normalized and tempered.

Carbon Per Cent	Manganese Per Cent	Silicon Per Cent	Vanadium Per Cent
0.45-0.55	0.70-0.90	0.15-0.25	0.15-0.20

	Carbon Steel	Vanadium Steel
Tensile Strength (lbs. per sq. in.) ..	83,000 to 93,000	92,000 to 105,000
Yield Point (lbs. per sq. in.)	43,000 to 53,000	60,000 to 70,000

Specified Minimums
Tentative A. R. A. and A. S. T. M.

Tensile Strength	83,000 lbs. per sq. in.		90,000 lbs. per sq. in.
Yield Point 52% =	43,000 lbs. per sq. in.		60,000 lbs. per sq. in.
Carbon	0.40 to 0.55 per cent	Carbon	0.45 to 0.55 per cent
Manganese ..	0.60 to 0.90 per cent	Manganese ..	0.75 to 0.95 per cent
		Vanadium	0.15 per cent

As further evidence to sustain my contention that the strength and high yield ratio are not due to any slight increase in the percentage of manganese, I submit the following comparative tests.

Forged 2½-inch rounds normalized at 1600 degress Fahr. and tempered at 1110 degrees Fahr.

Carbon	0.44 to 0.50 per cent	Carbon	0.45 to 0.50 per cent
Manganese ..	1.54 to 1.56 per cent	Manganese ..	0.75 to 0.80 per cent
		Vanadium ...	0.18 per cent
Yield Point	63,000 lbs. per sq. in.		75,000 lbs. per sq. in.

Cast steel locomotive frame coupons annealed at 1560 degrees Fahr.—furnace cooled.

Carbon	0.27 per cent	Carbon	0.27 per cent
Manganese	0.61 per cent	Manganese	0.69 per cent
Silicon	0.25 per cent	Silicon	0.26 per cent
		Vanadium	0.20 per cent
Tensile Strength	69,400 lbs. per sq. in.		73,100 lbs. per sq. in.
Yield Point	39,330 lbs. per sq. in.		47,600 lbs. per sq. in.

With reference to locomotive axle failures due to thermal cracks, mentioned in Mr. Fry's conclusion, I believe that too much emphasis cannot be given to the fact that such failures are caused by deficient lubrication. That thermal checking can be overcome by any other means than good lubrication is quite improbable.

Written Discussion: By M. A. Herzog, chief chemist, St. Louis-San Francisco Railway Co.

In the section of his admirable discussion of locomotive forgings dealing with the structure of the finished forging, Mr. Fry mentions the banded type of structure often found in carbon steel forgings, and expresses the opinion that such ferrite bands are in no way detrimental to the strength of the steel. Opinions differ on this subject.

Considering the frequency of this phenomenon in forgings and its often spectacular appearance under the microscope it is surprising that there is such a dearth of information on the properties of banded as against unbanded steel. No systematic study of the effects of ferrite bands in forgings appears to have been made; and forging manufacturers seem to have avoided rather than sought to throw any light on this matter, apparently in accordance with the axiom that it is better to allow sleeping dogs to lie undisturbed.

While there are many metallurgists who agree with Mr. Fry in dismissing bands as having no bearing on the quality of the forging there are others who believe that banded steel may be inferior to unbanded in resistance to fatigue. It seems quite possible that the effect of numerous well-developed bands of carbonless, and therefore relatively soft, iron embedded in the harder matrix of the carbon-containing portions of the steel would be to reduce the endurance limit of such steel under reversal of stress because of the possibility of the initial fatigue crack starting in one of these ferrite masses, which are often large when compared to the grain size of the steel. Such an occurrence is made more probable by the frequent presence in bands of nonmetallic inclusions of considerable size, which may act as stress-raisers and initiate microscopic cracks in the ferrite mass, which it is fair to assume has a considerably lower endurance limit than the carbon-containing metal adjacent. Internal discontinuities in metals are known to adversely affect their strength; and a band in a steel forging is in effect a discontinuity where a hard and strong metal adjoins one weaker and softer.

Mr. Fry states that physical tests have not shown that banding adversely affects the strength of steel. From the nature of banding one would not expect ferrite bands to appreciably affect tensile test values in bars cut with their axes parallel to the direction of extension of the forging, but if as contended above the junction of band and matrix is in effect

a minute plane of weakness their presence should be reflected in lower values for tensile test bars cut transversely to the direction of forging extension, owing to the greater effective area of the bands in specimens so cut. We have found this to be the case, for in all transverse tensile tests of markedly banded steel made by us we have obtained appreciably lower yield point and tensile strength values, and decidedly inferior ductility as shown by reduction of area and elongation, accompanied by fractures of characteristically "woody" appearance. Forgings free from banding, on the other hand, may give almost as high values in transverse as in longitudinal tensile tests.

Some forging manufacturers admit that banding is objectionable in forgings which are to receive transverse stresses in service, such as gun forgings, but claim that bands are harmless in forgings which will be stressed only longitudinally, as for instance locomotive piston rods. Such an admission is sufficient to cast considerable doubt on the advisability of using heavily banded steel in important locomotive forgings, where stresses are high and complex.

The most direct way in which to settle the question of the effect of banding on the service value of forgings would be to run a large number of reversal of stress fatigue tests on banded and unbanded steels, both parallel and transverse to the direction of forging extension. Until definite proof is forthcoming from some such series of tests of the harmlessness of banding in locomotive forgings we will continue to require the substantial absence of ferrite bands in forgings supplied us.

Oral Discussion

G. W. QUICK:[1] The discussion of the factors in the manufacture and forging of steel that make towards satisfactory forging coming from a man of Mr. Fry's experience was greatly appreciated and enjoyed by the speaker. There are two minor points under the head of ingot structure I want to speak of, which, however, do not bear upon the general purport of Mr. Fry's paper. On page 10 in the last paragraph, the second sentence: "On the extreme outside can be seen traces of a light colored, noncrystalline skin," and on the next page it is referred to as a skin of chilled metal. I wonder if we agree that there is a noncrystalline skin of metal rather than a crystalline skin. Although the sulphur print and microexamination did not reveal the crystal structure, I was wondering what magnification Mr. Fry used in examining that area. The other point I noticed is on the same page, the next to the last sentence on the page, which I believe is in error. "The first crystals of steel which form at the coldest points on the sides of the ingot are comparatively low in the three segregating elements because these elements raise the melting point of steel." Carbon, phosphorus and sulphur are the three segregating elements referred to but we know that carbon lowers the melting point of steel.

ROBERT JOB:[2] Mr. Fry's paper is of great interest to those concerned with locomotive operation owing to his clear description of methods and also his

[1]Member A. S. S. T., assistant metallurgist, Bureau of Standards, Washington, D. C.

[2]Member A. S. S. T., vice-president, Milton Hersey Company, Ltd., Montreal, Canada.

suggestions toward betterment of service. Some of the points, naturally, are open to argument, as, for instance, the relative merits of acid steel and of basic steel, but it is not our purpose at the present time to discuss this aspect. It should be remembered, however, that "good" or "bad" are relative terms, and that if better results are obtained with steel made by any given method of manufacture—whether acid or basic—it should be possible with the aid of present-day metallurgical knowledge to show the precise cause for the difference in service, where and when this exists and to take steps to secure the desired quality.

There may be little or no difference in chemical composition, as mentioned by Mr. Fry, but when steel is cleaner and less likely to be affected—other things being equal—by fatigue stresses, would not such condition be indicated by improved transverse tensile properties, and particularly by an increased ratio in ductility, as shown by elongation and reduction of area? In other words, should it not be possible to bar out inferior quality by means of carefully regulated physical tests? Such procedure would place no handicap upon any process, and would at the same time be an incentive to any manufacturer to so regulate the details of his method of manufacture as to reach the specified standard.

In this connection we have been greatly interested for some time past in investigating the properties of some quenched and tempered driving axles and crank pins which were placed in service last Fall upon the Canadian National Railways.

The steel was made by a well known English manufacturer by the acid process and the results of some of the tests may be of interest as a matter of comparison with those given by Mr. Fry.

Chemical	12-inch Axle Bored 3½-inch Per Cent	10-inch Crank from Solid Per Cent
Carbon	0.27	0.41
Phosphorus	0.037	0.043
Manganese	0.75	0.72
Sulphur	0.044	0.050
Silicon	0.15	0.20

Physical	Ratio* (See note below)	Ratio
Tensile strength in lbs. per sq. inch	86,480-105%	90,800-101%
Yield Point	49,080-107%	48,900-100%
Elongation	27.7%- 61%	25.0%- 72%
Reduction of Area	58.6%- 50%	52.1%- 55%
Izod. ft. lbs.,	30 - 60%	21.0%- 57%

*Ratio: This is the ratio existing between the properties of the test pieces taken transversely, as compared with those taken in the direction of rolling. The sections were cut midway between outside and center.

In these tests the relatively low carbon in the axles is of interest, with fairly high manganese, combined with good tensile strength and elongation and very good reduction of area. Also there is a fairly good ratio in elongation and reduction of area in the transverse direction, and little "woody structure" on the broken ends of the transverse test pieces. Time will demonstrate the service.

On page 20 of Mr. Fry's paper mention is made of banded structure, ghost lines etc., and attention is called to the excellent article in the *Metallurgist*, August, 1926. This is a moot subject, and we have no wish to become arbitrary or to draw unjustified conclusions. Mr. Fry states that he can remove

this structure by careful annealing, and our preference is that this structure should not be present. It should be noted also that a seamy laminated condition may sometimes be termed "banded structure" and we decidedly object to laminations in important locomotive forgings. Not long ago we had occasion to investigate a heat treated tire which had failed in service and we found a clearly defined "banded structure" similar to that shown by Mr. Fry. This is the only instance in which we have found this structure in a tire.

Another interesting statement on page 23 merits careful thought. Mr. Fry states: "Vanadium and other alloys, while improving good steel, cannot remove the fundamental defects of poorly made steel" . . . . "they require the maximum of care in manufacture to produce good results." Mr. Fry is entirely correct, for it is a well-known matter of observation that upon one road an alloy may be blamed for bad service of forgings whereas upon another line this same alloy may be used with excellent results. As Mr. Fry implies, there are many factors required in order to secure good service, and it certainly behooves the alloy manufacturer in such a case for his own protection to determine as definitely as possible the exact cause of any such failures since the alloy may or may not be responsible for the difficulty.

I do not wish to prolong this discussion, but will make brief mention of the important subject of heat cracks, noted by Mr. Fry on page 32.

The lubrication of driving axles and of crank pins is not by any means ideal, and for driving journals, grease is used which often is so stiff that a pressure of from 20 pounds or sometimes even 30 pounds is required to force the cap of a fountain pen (0.4 inch diameter) one-half inch into the grease in one-half minute. Under such conditions regular feeding is difficult. The running temperature of the axle may be about 250 degrees Fahr. and in events of carbonizing or blocking of the holes in the plate the temperature may range much higher. Under such conditions a different type of steel is necessary in order to secure reasonably good service from what could be utilized if a different system of lubrication were devised giving lower running temperatures, and under the latter conditions far greater advantage undoubtedly could be taken of special alloys and of special methods of heat treatments.

In conclusion I wish to compliment Mr. Fry upon his interesting and carefully considered paper.

C. H. Herty, Jr.:[3] In connection with Mr. Batty's remarks and Mr. Furness' remarks, and a sentence in Mr. Fry's paper I would like to bring just one thought particularly to the men who have an opportunity for carrying on research work. In Mr. Fry's paper the following statement is found on page 5: "The effect of these additions is to carry out a final deoxidation and to 'kill' the steel, that is, to drive off"—notice that—"to drive off or absorb gases which the steel would otherwise contain."

Mr. Batty thinks that the blowy condition or the blistering condition in the steel that we are speaking of now is due to the introduction of atomic silicon into the gas which in some way imbues the steel with the property of holding a lot of gas in solution. Now just why silicon reduced from the slag

[3]Member A. S. S. T., supervising metallurgist, metallurgical department, U. S. Bureau of Mines, Pittsburgh.

should act differently from ferrosilicon put into the bath is a little beyond me. I wonder this—we talk about nonmetallic inclusions, we talk about slags, and everything else, and when we come to gases in steel we say we think gases do this, or we suppose they do, or that the steel is imbued with certain properties due to various things. It seems to me that it should be a very easy job to do some solubility determinations on gases in liquid steel. It has been done on hydrogen, it has been done on nitrogen. Why isn't it possible for someone to get a program on gases and steel where one would study the solubility of gases under different conditions in the steel bath? For example, take a pure iron and then add silicon, and see what effect silicon gives. I think the whole discussion on gases could be answered by a good two years' work on how gases act when the metal solidifies. One of the discussers of Mr. Fry's paper stated that we should be able to counteract a great number of points he raised in connection with forgings, but I think this gas in steel proposition is a mighty fine example of how little we really know. I believe that 90 per cent of the things put down in papers are opinions and have no experimental basis. As far as I know there is not a single piece of work going on on gases in liquid steel in this country. Lots of people have written on gases in solid steels and that, of course, is an awfully backward way of doing things. What one should do is to find out what happens to gas in the furnace while the steel is liquid and while it is solidifying. If we get a few data on these subjects I am sure you will be able to find an answer to many of the questions you are asking Mr. Furness and Mr. Batty.

Author's Closure

It is encouraging to have had so much discussion of the paper, and it is gratifying to find so little disagreement with the main principles laid down. Mr. Edwards quotes me as saying that in plain carbon steel "the manganese content should range from 0.55 to 0.70 per cent." Evidently Mr. Edwards is referring to the next to last paragraph on page 22, but if he re-reads this he will find that the statement made there is that certain average tensile results were obtained from a group of forgings which had a manganese content of from 0.50 to 0.75 per cent. So far as residual chromium and nickel in plain carbon steel are concerned, I fully agree with Mr. Edwards that the limits set in the new A. R. A. specifications are unnecessarily low. There does not seem to be any reason why chromium up to 0.25 per cent and nickel up to 0.40 per cent should not be acceptable. The effect of even these quantities would be practically negligible.

When Mr. Edwards says that my statement regarding carbon-vanadium steel forgings must be qualified, I must ask him to re-read the paper and more carefully. He says that it would not be possible in a plain carbon steel to obtain "the high yield point and the high ductility which are obtained with normalized carbon-vanadium steel." I agree, but what the paper said was that carbon-vanadium steel "owes its strength and high yield ratio to the manganese content while the vanadium ensures....ductility." Mr. Norris questions this statement, but the evidence he offers in rebuttal is not very strong, as it consists mainly in quoting the range of the tensile properties found in carbon steel

and carbon-vanadium steel forgings. My conclusions are based on two main bodies of fact. Some years ago I collected several hundred tensile results from plain carbon steel forgings all of the same size and subjected to similar heat treatments. The carbon ranged from about 0.40 to 0.50 per cent and the manganese from about 0.50 to 0.80 per cent. It was possible with this large group of data to see how a variation in manganese content affected the tensile properties. There was a clearly marked tendency for an increase in manganese to give increased tensile strength and yield point without any noticeable lowering of the ductility. Recently we have had opportunity to test several heats which had a high manganese content with no vanadium. The following figures are representative of the results obtained:—

Heat	Carbon	Manganese	Yield Point	Tensile Strength	Elong. in 2"	Red. of Area	Material
A-1225	0.38	1.34	63,000	102,000	22.5	41.0	Casting
A-1652	0.41	1.44	64,000	98,000	22.0	45.0	Casting
A-1652	0.41	1.44	66,000	103,000	23.0	43.5	Shaft
A-969	0.51	2.02	57,500	105,000	24.0	45.0	Driving Axle
A-1433	0.50	1.44	66,500	100,000	22.0	40.5	Casting
A-1433	0,50	1.44	59,000	98,000	24.0	51.0	Shaft
26356	0.48	1.00	61,500	106,000	20.0	39.0	Conn. Rod.
23674	0.51	1.17	65,000	105,000	21.5	40.5	Shafts
22570	0.51	1.19	67,000	108,000	21.0	40.5	Driving Axle
23183	0.49	1.18	55,500	103,000	21.0	40.5	Driving Axle
Average			62,100	103,000	22.0	43.0	

The material represented was normalized and annealed, and except for the high manganese was plain carbon steel. If the values of tensile strength and yield point are compared with those quoted by Mr. Norris or with the average values given on page 22 of the paper, it will be seen that the high manganese content gives high tensile strength and high yield ratio. Experience with the high manganese plain carbon steel has shown, however, that it cannot give the grain refinement and consequent ductility which are obtained so satisfactorily when vanadium is added. I am convinced that carbon-vanadium steel owes its ductility to vanadium, but that the major part of its excess strength is traceable to the high manganese content.

Mr. Quick is quite correct in taking exception to the outer chill skin on the ingot being described as "noncrystalline." The paper should have said that this skin was composed of finely grained steel which did not show a crystalline structure on sulphur printing or macro-etching. Though accepting this correction, I cannot agree with Mr. Quick that the account given of the freezing of the steel is incorrect. Carbon, as Mr. Quick correctly says, lowers the melting point of steel. Because of this, as the steel is cooled, the low carbon metal freezes first, that is at the highest temperature.

Dr. Barr compares steel making with surgery. The comparison is apt. Both are arts, but both to succeed must rest on certain fundamental scientific principles. The surgeon with all his skill must use asepsis, the steel maker must reckon with conditions some of which have been outlined in the paper.

Mr. Job points out that it would be desirable to establish tests which would of themselves differentiate well made steel from badly made steel. Unfortunately our knowledge is not yet wide enough to enable us to do this. It may be done to a certain extent by the etching tests described by Mr. Edwards,

but these do not tell all of the story. It remains important as Dr. Barr has said to choose a source of steel supply on the basis of "known skill and integrity." Mr. Job gives particulars of some English axles being tried by the Canadian National Railways. These are comparatively low in carbon content, quenched and tempered. The high ratio of transverse to longitudinal tests indicates a well made steel. It should be remembered, however, in considering these figures that in this country the tendency of the railroads has been to move away from the use of quenched forgings. With the smaller sections used in Europe quenching is less objectionable than with the large diameter forgings necessary here.

Mr. Herzog contributes an interesting discussion of banded structure and advances the view that the ferrite bands may be softer than the remainder of the steel, and may therefore reduce the fatigue strength. If this were true the ferrite bands should reduce equally the tensile strength, particularly in the transverse direction. Transverse tensile tests on banded material do not show much reduction of strength. Also it should be remembered that in failure by fatigue as well as in failure by direct tension the fracture does not originate in and follow the ferrite network. Failure originates in the grains and travels across them, indicating that the ferrite does not necessarily indicate a line of weakness. In discussing banded structure care must be taken to differentiate between the ferrite bands shown in Fig. 8-A and the large bands of nonmetallic inclusions found in poorly made steel. Large nonmetallic inclusions undoubtedly constitute points of weakness. These remarks answer also Mr. Laudig's remarks on banding. Large inclusions are undesirable whether or not accompanied by ferrite bands, but ferrite bands without inclusions have not yet been shown to be deleterious.

Mr. Higgins is correct in saying that the production of good forgings depends not so much on the choice of acid or of basic steel, but on the selection of fundamentally sound steel. Good steel can be made by both the acid and the basic process, but as the acid slag is a better deoxidizer than the basic slag and as it provides the melter with a definite gage for the amount of deoxidization of the steel, it is easier with the acid process to make good steel and to make it consistently.

Mr. Kuhn contributes some valuable notes on the mechanical handling of forgings by the railroads. If a solution is to be found for the difficult problems presented by powerful modern locomotives in intensive service, it is essential that the mechanical engineers assume their full share of the burden. It is poor engineering to ask the metallurgical engineer to develop new and expensive steels to overcome troubles which could be corrected by elimination of sharp fillets, poorly machined surfaces and faulty lubrication.

PREPARATION OF MICROSECTIONS OF TUNGSTEN CARBIDE

By Samuel L. Hoyt

Abstract

This paper discusses a method of preparing cemented tungsten carbide for metallographic examination. A procedure is described which has proven to be rapid and efficacious. The successive steps are: (1) smooth grind with silicon carbide wheel, grade 60-I or 100T; (2) lap on copper disk with 140 to 200 mesh boron carbide moistened with kerosene; (3) lap surface with No. 7 diamond dust on wooden lap and finish with No. 9 diamond dust. Time of lapping has been found quite important.

CEMENTED tungsten carbide is so hard that the usual methods of preparing microsections are not convenient and satisfactory. A procedure is described here which has proven to be rapid and capable of producing a high polish which is free from scratches at high magnifications.

The sample to be sectioned can be cut with a diamond saw, or it can be broken off at the desired section and the face ground smooth on a silicon carbide wheel. If facilities for surface grinding or automatic lapping are available, the surface can be easily trued up preparatory for the final lapping and polishing. We have found that wheels of grade 60-I are satisfactory for grinding cemented tungsten carbide products. Detroit Star 80H and Carborundum 100T have been found to give excellent results, while other similar wheels may be expected which will give equally satisfactory results.

The next step is that of lapping the surface on a copper disk with boron carbide powder which is moistened by kerosene. This operation grinds up the lapping powder finer and finer as lapping progresses so that it is desirable to gage the amount of powder properly for the amount of work to be done. If the correct amount is used, the surface will be rapidly cut down at the start and the coarser scratches from grinding removed, while later lapping will produce a

A paper presented before the Eleventh Annual Convention of the Society, Cleveland, September 9 to 13, 1929. The author, Dr. S. L. Hoyt, member of the society, is associated with the research laboratory of the General Electric Company, Schenectady, New York. Manuscript received June 9, 1929.

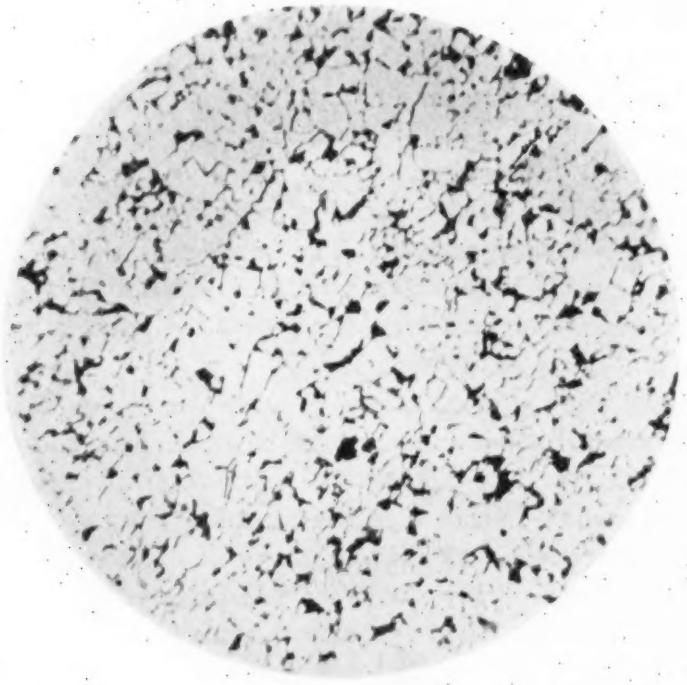
fine velvet-like, surface with only very small imperfections. The powder used runs from 140 to 200 mesh, while we have found that in some cases a fine powder of under 200 mesh is desirable for finishing the operation. This is particularly true for large surfaces of around one inch in diameter.

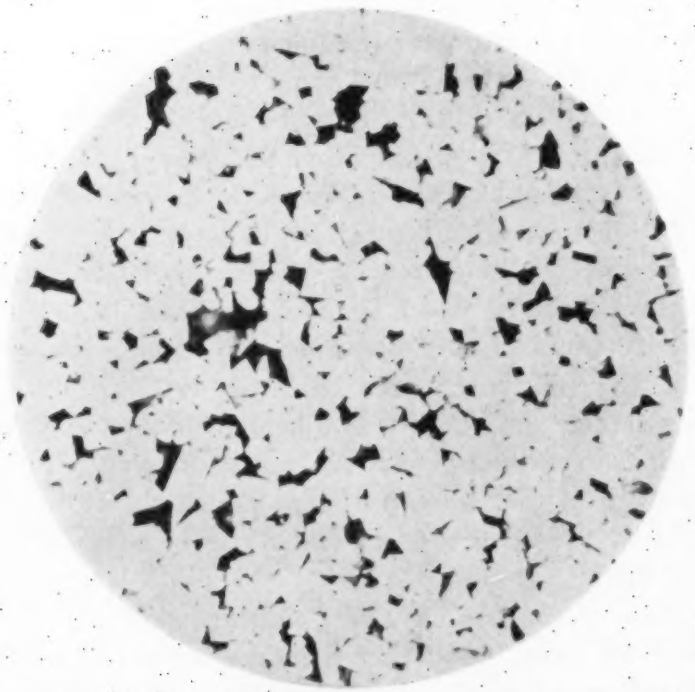
The copper disk used is about eight inches in diameter and runs at 150 revolutions per minute. The surface of the disk should be machined as smooth as possible, and then polished with a fine emery paper. A smooth surface prepared in this way makes it possible to lap faster and gives better results.

We first tried silicon carbide powder for lapping but our tests have shown that it is not as fast as the boron carbide, and that it loses its cutting ability much quicker. Perhaps the most serious defect with silicon carbide is that it leaves the surface rough. This is evidenced by the rather dark appearance of a surface which has been lapped with silicon carbide, whereas the surface lapped with boron carbide has a more polished appearance, with a velvety lustre.

The surface is next lapped with fine diamond dust on a wooden lap with almond oil. This lap is about six inches in diameter and also runs at 150 revolutions per minute. The almond oil is heavy enough to keep the diamond dust from flying off the lap. The diamond dust is what we call No. 7 grade, and is actually about 1.5 to 2 mu. in diameter. Its settling time in almond oil is about eight weeks. This is about as fine powder as can be readily obtained, but it may not be fine enough for much of the work which must be done, especially at the high magnifications. For this latter work we have a special grade made up which is called No. 9 and which runs about 0.5 mu, or 0.00002 inches in diameter. Its settling time would correspond to over one year. The No. 9 dust follows up the No. 7 simply to complete the polish. The amount of No. 7 which is used is about what one would get on the end of a tooth pick while only about one tenth of that amount of No. 9 is used. In the latter case we have placed a piece of medium heavy paper on the lap and lapped directly on that.

The time of the lapping and polishing operations is quite important and we have found that the time consumed for the boron carbide and diamond lapping is not over five minutes when the sample is of the order of one quarter inch square. Previous to the development of the technique described here, we have spent hours on





Figs. 1 and 2—Photomicrographs of Two Trial Lots of Cemented Tungsten Carbide. Polished with Diamond Dust, Etched in a Solution of Three Parts of 30 Per Cent Hydrofluoric Acid and One Part of Concentrated Nitric Acid for One Minute, Followed by Boiling 4 Per Cent Hydrogen Peroxide for Five Minutes. × 1000.

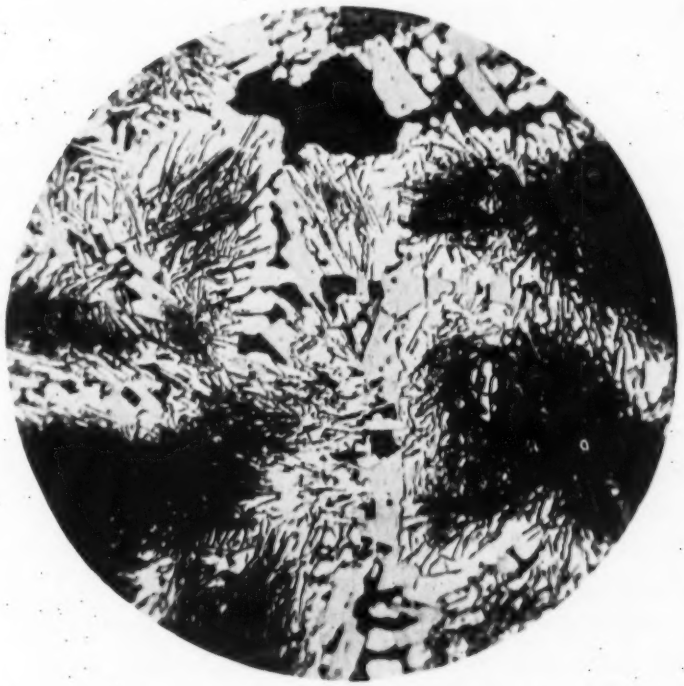


Fig. 3—Cast Tungsten Carbide, Polished with Diamond Dust and Etched the Same Way as Figs. 1 and 2. × 1000.

this work with anything but satisfactory results. In fact, we have found that other methods are only too apt to efface the true structure and give anything but a true representation of the size and shape of the particles and the nature of the cementing material. It may be of interest to note that we have tried silicon carbide papers, tungsten carbide papers, silicon carbide hones and softer hones, alumina, etc., either as papers or as a powder, and even sand stone. These are either too slow or else they give poor results. For example it does not seem possible to produce a real polish on cemented tungsten carbide with silicon carbide in any form.

Some of the special points which have come up in connection with this study of the methods of preparing microsections of cemented tungsten carbide may be of interest. This material, in some of its forms, may have many small cavities which, of course, make a polishing operation of the character under discussion very difficult. Polishing or lapping material gathers in these cavities, to produce disturbing effects, while the edges are only too apt to round off. Another difficulty arises from the circumstance that, after all, cemented tungsten carbide is not a forged metal but is a sintered prod-

uct composed of hard, brittle, particles. Here and there are little clusters of grains which are apt to be gouged out, much the same as grains of a hard intermetallic compound which are held in softer matrix. An additional effect which interferes with the production of a polished surface free from defects arises from the tendency of the matrix itself to chip out. The pits left are extremely small and are to be seen only under the microscope and, in fact, all of these effects relate to the minute microstructure of the material and have little practical significance in the use of the material. As a matter of fact, the polished surface of a sample of cemented tungsten carbide is a very pleasing mirror, free from visible defects.

A few photomicrographs are included to show the results obtained with this method of preparing microsections of tungsten carbide products. Two excellent etching reagents for these materials have been published by J. L. Gregg and C. W. Kuttner.[1] These reagents and boiling hydrogen peroxide have been used in the author's work, and particularly the one made by mixing three parts of 30 per cent hydrofluoric acid and one part of concentrated nitric acid. The peroxide etch is apt to dissolve out some of the finer particles to give an effect like that shown in Fig. 2.

It is a pleasure to record the assistance of H. C. Staehle in developing the methods described here and in obtaining the photographic illustrations.

DISCUSSION

Written Discussion: By J. R. Villella, Union Carbide and Carbon Research Laboratories, Long Island City, N. Y.

Dr. Hoyt's contribution is a practical solution of a difficult problem.

Finishing with diamond dust on a hard lap is essential to obtain a true picture of the structure. Other abrasives on cloth laps gouge out the hard particles of tungsten carbide, causing a false porous appearance. This has been realized for some time, and though no attempt was made to work out a finished method, we have been polishing our specimens more or less as Dr. Hoyt recommends. The samples are ground flat with a fine carborundum wheel, and then taken to a diamond cutter for the final polishing. The entire operation does not take more than thirty minutes of actual work.

Dr. Hoyt's method can be easily carried out in any laboratory with standard metallographic equipment and is indeed, a great improvement, for none of the specimens I ever examined were as free from scratches as those shown in his paper.

[1] J. L. Gregg and C. W. Kuttner, "A Metallographic Study of Tungsten Carbide Alloys," American Institute of Mining and Metallurgical Engineers. Technical Publication, No. 184, February, 1929.

THE SLAGS PRODUCED IN STEEL MAKING—THEIR EFFECTS ON THE PRODUCT AND ON THE PROCESS ITSELF

By George A. Dornin

Abstract

In this paper the writer calls attention to the inevitable flaws and lack of reliable uniformity that must follow in steel made by processes that attempt to finish and refine under slags carrying iron oxides.

Iron oxides are present in the finishing slags of all processes making steel today except the basic electric with its reducing calcium carbide slag. This seems to be costly and slow and therefore available only for high cost operations.

Acid slags are less oxidizing than basic slags but their field is very limited.

The writer does not believe that reducing slags are necessary but only that the finishing slag must carry no iron oxides; that the reduction of FeO in the bath can be accomplished most cheaply in a big way by the addition of deoxidizers which must be so done that FeO is not fluxed out into the slag.

STEEL making is basically and fundamentally a refining process. The reason for its being, its usefulness, lies wholly in that by refinement it is possible to get stronger and more reliable metal for the use of man. The making of steel crudely and in small quantities is quite old but most of the progress in steel metallurgy is comparatively recent and with its development has come our present civilization based on steel in which due to machinery a comparatively small part of the population is able to produce food and clothing ample for the whole, thus freeing the majority to produce other things wanted, the so-called luxuries, though today probably the necessities of our modern life.

When one realizes that up to about one hundred years ago the transportation available to man was just about what it had been as far back as we have any reliable history, that for many thousands of

A paper presented before the Eleventh Annual Convention of the Society, Cleveland, September 9 to 13, 1929. The author, George A. Dornin, member of the society, is associated with the Gathmann Engineering Co., Baltimore. Manuscript received June 3, 1929.

years man had made no real progress until steel began to be available, that our whole present civilization is based on steel, one must see the vital part that the reliability of our steel supply plays in the lives of all of us.

It is through the slags produced and used in all of our steel making processes that this reliability is in its initial and probably its major phases controlled. In steel the product desired is one free or as free as possible from oxides. Inasmuch as the element iron, the basis of steel, oxidizes very rapidly when molten, if a bath of molten steel is not protected from atmospheric oxygen it will fast undo the previous effects of refinement and the slag therefrom must be in the final phase, the cover or blanket which protects the metallic bath from this influence.

All slags are made up of oxides, and these being in every case lighter than the bath the slag floats on top thus performing its functions of protection. Furthermore, of all the oxides that go into the makeup of a slag only one, namely FeO, is oxidizable by atmospheric oxygen and only this same, FeO or Fe_2O_3, has any direct oxidizing effect on the bath under it. It would seem logical therefore if we are to have reliability, that is, cleanness and uniformity, in our steel production that the molten bath for a sufficient time before teeming or casting should be under a slag blanket that has in it no FeO. With minor exceptions this is not the case and I propose in the following to point out where it is and is not done, state why, and call attention to the inevitable flaws or lack of reliability that must follow this neglect.

Steel making processes may be classified under two general heads.

(1) Processes which do not oxidize but which confine their effects to the removal of oxides already present when the charge is made up, and to detrimental elements such as sulphur which is removed by absorption into the slag.

(2) Processes which take unwanted elements out of the charge by oxidizing them and allowing them to pass from the bath to the slag by flotation. This can be done only by the introduction into the bath of FeO either directly as in the oreing of an open-hearth or indirectly as in the blast of a Bessemer.

The first type of process depends for its being upon a supply of iron or steel scrap previously made by some other steel-making

process and only melted down and refined in this process and its usefulness is thus limited though its products where it can be applied are, or at least can be, of the highest quality.

It is, with the present day development of metallurgy, upon the second type of process that we must rely for the greater part of our steel supply. These processes and there are two, Bessemer and open-hearth, both of them operated either acid or basic when run in conjunction with a blast furnace make steel out of ore, and therefore, must be our main reliance for supply. The acid process does not remove either phosphorus or sulphur, both are detrimental elements in steel, except in minor cases, and our ores and fuels carry both in material amounts so that the field of the acid process is sharply limited.

We must depend therefore mainly upon basic processes for our supply and here again we are limited to the open-hearth because the Bessemer has and can have nothing but an oxidizing phase, its reducing and refining phase being so limited that it can hardly be said to have any. Its usefulness therefore is confined to the production of products where quality and reliability are secondary to price and our choice narrows down to the basic open-hearth for the major part of our steel supply.

Let us analyze this basic open-hearth process upon which we are so largely dependent and try to find out its possibilities and limitations. It is first of all a very flexible process as it can make steel out of almost any available supply of metallic charge, iron or scrap, and in almost any proportion of the two. It can eliminate elements other than iron from the bath to a point where this is well over 99 per cent iron. It can do this rapidly and cheaply. It is a highly efficient means of oxidizing and furthermore its rate of oxidizing is pretty well under control because it can be hastened or slowed up. Its tool, the regenerative furnace, gives temperatures much higher than the furnace linings will stand.

Having performed its oxidizing function, we find, however, that this has been accomplished by building up a slag blanket carrying a high percentage of iron oxides FeO and Fe_2O_3. When we try to deoxidize and refine the bath under this slag we at once encounter troubles because we are trying to carry out refinement or deoxidizing under conditions which are highly oxidizing and which we cannot change from highly oxidizing as long as we leave this slag on the bath. The total of iron oxides in the slag tends to constantly increase due

to the oxidizing effect of the furnace atmosphere on the FeO in the slag and it is not possible to reduce these iron oxides materially because anything that did this would also drive phosphorus back into the bath. It would seem therefore that if we are to have efficient deoxidation and refinement we must separate the bath from this oxidizing slag and arrange to do it under more favorable conditions.

Up to the present time the only worth mention attempt to do this has been with the tilting electric furnace and here it was probably done in an inefficient way because the first, or oxidizing slag, was skimmed from the bath instead of tapping the bath from under the slag. Some tonnages of steel also have been made by carrying out the oxidizing phase in the basic open-hearth and finishing or refining and desulphurizing it in the basic electric furnace under a calcium carbide slag, which is reducing and therefore proper for finishing. With these minor exceptions and also the tonnage made in the electric furnace by melting scrap under a reducing slag, all of our present day steel supply is finished under slags that carry material amounts of iron oxides varying from as low as 6 per cent or 7 per cent in the acid slag of the crucible to as high as 25 per cent and sometimes even more in the basic open-hearth.

When steel is finished under these conditions the penalties and lack of reliability follow automatically, for either we wind up with a bath full of gas and iron oxide, the flaws resultant being well known, or if we deoxidize we can only turn these gases and oxides soluble in the bath to an insoluble form, hoping that we will form these insoluble oxides in such proportions that they will flux each other and thus grow by colloidal action to where they will float up out of the bath. If this does not properly happen we have dirty steel.

Even if the heats are very carefully worked to a point where the carbon and iron oxides of the bath are in equilibrium with the iron oxides in the slag, and this in practice is rarely accomplished, as soon as we attempt to deoxidize the bath we break up this equilibrium and iron oxide at once begins to dissolve back from slag to bath attempting to undo the deoxidation already done. While this is going on there is the tendency of the FeO in the slag to turn to Fe_2O_3 in contact with the oxygen of the flame and here we can only oppose this by turning the air up the stack of the open-hearth and letting only the gas go over the bath, thus getting the softest or most reducing flame possible. During this period the whole operation tends to cool down. In other words, in the basic open-hearth as run

today we can have only a temporary equilibrium and a limited refining phase if we finish under an oxidizing slag and the results obtained therefore are very largely dependent upon the judgment and skill of the operator and as the skill of operators differs widely the quality of the product shows just as great a variation.

What can we do and what tools have we in being today that will aid us? Having gotten our required bath composition we must separate the bath from the oxidizing slag covering it and fortunately we have a thoroughly tried out tool which it seems to me gives us a chance to accomplish what we want. This is the tilting furnace and by its means we should be able to draw the bath from under the slag without any contamination. It is not possible to properly skim the slag off the bath. A heavy fluid can be drawn from under a lighter fluid without causing mixture while a light fluid cannot be taken off the top of a heavier one. Milk and cream form a fair example of this.

Having taken a bath of steel away from the oxidizing slag that produced it we must at once protect it from atmospheric oxidation and this means a slag cover free from iron oxides. There is no good reason why this slag cover of any desired composition should not be melted and ready for immediate use. The bath can now be properly deoxidized and refined for we have slags in operation today that do this. I refer to the calcium carbide slags in the electric furnace. This is reducing and if carbon and temperature be maintained, complete reduction of all oxides in the bath must eventually take place provided the bath is so agitated that all parts of it come in contact with the slag. This takes a long time, is costly and from these standpoints is unsatisfactory.

The oxides in the bath at the end of the oxidizing phase are or should be almost entirely soluble oxides and can be very rapidly turned to insoluble forms by additions of which silicon, manganese and aluminum are the most used and best known. These oxides if present in the proper proportions flux each other rapidly, grow by colloidal action and float out of the bath into the slag. This takes place fairly rapidly, the only things necessary to permit its accomplishment being temperature to maintain fluidity and agitation to promote colloidal action.

One phase of the reduction or change of soluble oxides to insoluble form must be kept in mind. This must be so done that the insoluble oxides thus formed do not flux FeO. The deoxidizer must

reduce FeO otherwise we will get FeO into the slag where it can be oxidized by the flame thus building up. Research now under way with the three deoxidizers afore mentioned should give us the knowledge necessary to carry out the deoxidations as just outlined and I see no good reason why the basic open-hearth process cannot be operated along the lines laid out and thus be changed from a process having in its refining phase only temporary equilibrium and limited refining to a process having permanent equilibrium and unlimited refining.

It is to promote thought along these lines that this paper has been written.

DISCUSSION

Written Discussion: By H. W. Gillett, director, Battelle Memorial Institute, Columbus, Ohio.

The change of slag suggested by Mr. Dornin is logical. A chemist trying to extract something, let us call it X, from aqueous solution by means of ether would not hope to complete the extraction with ether itself charged with X; he would put the solution in a separatory funnel, draw if off from the X-charged ether and use a new portion of X-free ether. The distribution coefficient is acting against him unless he does so. The removal of FeO dissolved in steel is analagous and would be favored by the use of fresh, FeO-free slag.

Mr. Dornin properly points out that he wants, in the final deoxidation, to get rid of all FeO so as not to introduce it into the final slag cover, and allow further oxidation of FeO at the surface of the slag to Fe_2O_3. He wants to protect the underlying metal from oxygen in any form that can go back to the metal. If we are considering the ideal, leaving just how to accomplish that ideal for future consideration, should we not pay more attention to the FeO content of the bath below the final slag cover?

Mr. Dornin suggests that a truly reducing (CaC_2) slag will eliminate the FeO of the bath if given time. Unfortunately, before time enough can elapse for truly complete elimination of FeO the basic bottom usually comes up, and its FeO content undoes some of the previous reduction. Hence it will be necessary to provide a FeO-free lining as well as a FeO-free slag.

If we use a neutral slag we must utilize the carbon of the bath as the initial deoxidizer. In high carbon steel true equilibrium such as Mr. Dornin wants to obtain would mean very low FeO in the bath, but unfortunately we sometimes want to make low carbon steel. Then we have to depend on metallic deoxidizers—manganese, silicon, aluminum, and the like. Perhaps when we know enough about it they can be so proportioned that the resulting oxides will be self-fluxing and will really coalesce and rise.

But to get fluxing we must have a complex deoxidizer, or at least

two metals, e.g., manganese and silicon. The two metals will not have the same heat of oxidization, one will be oxidized more rapidly than the other. Depending on the amount of FeO in the bath the ratio of MnO and SiO_2, for example, will vary. If the same amount of FeO is always present, a given manganese-silicon alloy can be added that will produce the proper MnO-SiO_2 ratio, but if the FeO varies, the ratio of manganese to silicon in the deoxidizer would have to be varied also.

The less FeO we have present before adding the final deoxidizer the less the volume of insoluble oxides formed. Why not consider getting rid of the FeO by carbon, forming CO instead of by metallic deoxidizers which form insoluble oxides? Mr. Batty's use of washed metal (preprint No. 4, p. 4) seems to be a step in the right direction but its application is limited at atmospheric pressure. At atmospheric pressure the reaction FeO plus C—Fe plus CO comes to equilibrium and to eliminate FeO, the C must be high. At reduced pressure, CO is taken away from the sphere of the reaction and, even with low C, the reaction would go nearly to completion.

If the transfer of the steel from the open-hearth were made to a high frequency induction furnace which was capped and put under vacuum, the elimination of CO would result in corresponding diminution of FeO. A low carbon steel under reduced pressure would approach the same equilibrium as a higher carbon steel under atmospheric pressure. Much less FeO would remain to be handled by metallic deoxidizers with resulting insoluble oxides to remain suspended and cause dirty steel.

This vacuum finishing of steel may sound impractical, but there is nothing to prevent the building and operation of vacuum high frequency furnaces (call them ladles if you like), holding several tons of steel. Rohn[1], in Germany, claims to have made 4-ton heats of nickel-chromium alloys, and says it is feasible to build a 30-ton vacuum furnace to operate at 1750 degrees Cent. (3180 degrees Fahr.). Pulling out other gases than CO, such as H_2 and N_2, would not be disadvantageous either. There is nothing to prevent using a CaC_2 slag in the induction furnace and letting that, as well as the carbon in the bath, act on the FeO. The automatic stirring inherent to induction melting would favor reaction at the interface of metal and slag.

While we need to know more about metallic deoxidizers, their oxide products and the ability of the latter for self-fluxing and agglomeration, what we do know indicates that getting self-fluxing will be a hair trigger operation. To avoid the necessity of eliminating FeO by such means, let us see how far we can go toward eliminating it by carbon, favoring that by vacuum. CO is the best possible reduction product of FeO for CO is a gas, and it wants to come out. All solid or liquid oxide products have so little difference in density from that of the metal that their urge to escape is much less. It will take less coaxing to get the CO out. If we favor formation and elimination of CO by evacuation of the finishing furnace, or ladle, we will be acting along the line of least resistance. It

[1]W. Rohn, "Technische Eigenschaften Vakeumgeschmolzener Metalle, *Zeitschrift für Metallkunde*, vol. 2, 1929, p. 12.

is only because we are not accustomed to vacuum finishing that the operation seems strange. When we take into account the possible reactions by which dissolved FeO may be removed from molten steel, what can be more nearly ideal than that of FeO plus C—Fe plus CO? Why not give that reaction a chance?

Carlin[2] states that the amount of CO present in steel before addition of manganese is a function of temperature only. It must, however, be a function of pressure when we operate at pressures other than atmospheric.

Cicero was accustomed to close all his talks with the statement that "Carthage might be destroyed." In discussion of papers on steel making such as those of Carlin, of Batty, and this one of Dornin's, I feel impelled to reiterate, "Vacuum melting ought to be tried."

Written Discussion: By C. H. Elliott, works manager, Republic Iron and Steel Works, Warren, Ohio.

Mr. Dornin's paper concerning slags produced in steel making, their effect on the product and of the process itself, calls attention to a field in which a great deal of study has been made in recent years. It has been only comparatively recently that the action of the slag upon the steel has been appreciated by the steelmaker himself. This, of course, has been due to the lack of intensive study of the composition of steel impurities and their source, and this knowledge is as yet incomplete, since in order to definitely correct an evil, the cause thereof must be definitely understood by the man who must solve the problem. For instance, the quality of the pig iron as regards impurities has not been definitely studied perhaps as it should have been, since there are certain impurities coming from a bad working blast furnace which undoubtedly present problems very difficult for the open-hearth man to correct. These blast furnace troubles are usually only temporary and in a short time correct themselves, due to the improvement in the working of the furnace and the skill of the furnaceman, and many heats have been spoiled since the steelman did not know that the blast furnace was temporarily performing its duties incompletely.

Many of the problems in the past of steel impurities have been laid to the scrap in the open-hearth furnaces, sometimes justly and sometimes unjustly, since it was thought that cheaper grades of scrap were in themselves detrimental to the production of good steel. Undoubtedly this has been true in some cases and in others any detrimental effect has been very difficult to discover.

Mr. Dornin asserts, and correctly, that the final slag of an open-hearth heat should be reducing, a condition that is impossible to achieve with the average slag in a basic furnace, and suggests the removal of the slag by emptying the furnace, probably into a ladle, and transferring the steel to a second furnace and the formation of a new reducing slag for finishing the heat.

He brings out the extra cost and the natural difficulties which would be encountered, and rightly so, since each extra operation of that sort

[2]J. E. Carlin, "The Physical Chemistry of Rimmed Steel," TRANSACTIONS, American Society for Steel Treating, Vol. 16, 1929, p. 293.

would be expensive and it is difficult except in cases of special steels, to increase the price of the product, since the tendency is to lower prices rather than higher, in all modern steel making. Another difficulty to be encountered in most operations as performed at present, would be to bring the steel in contact with this reducing slag, since in a reducing atmosphere of that sort there would be no boiling of the metal, which in itself is a mixing operation.

I do not believe that this problem is as yet in a position to be solved by our present methods. Deoxidizers, to be properly allowed to function, should by all means be added in the furnace, since it has been found in many cases that deoxidation in the ladle or in the ingot itself, has been in practically all cases unsatisfactory, since the products of deoxidization remain in the steel and have a tendency to collect in globules and cause trouble. These products of deoxidation when the operation is performed in the furnace, have a tendency as a rule to rise to the surface and are absorbed in the slag; however they naturally leave behind the oxides of iron, manganese, etc., which to a greater or less extent remain in the steel itself. These oxides also have a tendency to rise to the top of the ladle and also to the top of the ingot and can be partially eliminated by extra cropping in the blooming mill.

In order, however, to increase the yield from the ingot on good steel, it would seem that perhaps the most practicable way at present would be in a tilting furnace, the skimming of the highly oxidizing slag at the earliest possible moment, before the actual finishing of the heat, and the manufacture of a new slag to remove the oxides from the metal itself. This would not give as good results as the double furnace process suggested, but would be an improvement perhaps over the present method and has been tried in many cases. The tilting furnace offers undoubtedly the most effective method of separating the steel and the slag, and I believe that smaller sized furnaces than the present tilting furnace offer a better field for experiment along these lines than has been the case heretofore. A great deal of work must be done before this problem can be called settled, since our knowledge is not complete enough to lay out a definite program for the manufacture of perfect steel.

Written Discussion: By H. P. Evans, metallurgist, Pettibone Mulliken Co., Chicago.

Mr. Dornin has again introduced that very interesting and much discussed question of steel slags. Although he does not offer any concrete solution for the proper and most efficient method of refining open-hearth steel, he does catalog some of the major shortcomings of our existing methods and points the direction, but not the road, to improved practice. The subject is well timed and should promote an interesting discussion.

It seems well to summarize some of the points maintained by the author.

1. It is impossible to efficiently deoxidize the bath under normal basic open-hearth operating conditions since refinement and deoxidation must necessarily be accomplished under highly oxidizing conditions which

cannot be remedied so long as the slag is left on the bath. That the total iron oxide in the slag tends to increase constantly due to the oxidizing effect of the furnace atmosphere, and that any attempt to reduce these oxides will drive phosphorus into the bath.

2. It is impossible to properly skim the slag off the bath.

3. The separation of slag and bath can be attained without undue contamination by drawing the bath from under the slag.

4. This metal may then be refined in some manner of equipment under a reducing, or at least an iron oxide-free slag added to this bath.

5. This refinement will probably be accomplished by proper additions of such well known deoxidizers as silicon, manganese and aluminum in such a manner as to flux out the undesirable oxides by forming insoluble oxides in which FeO is insoluble.

6. The removal of oxides by a carbide slag such as is obtained in a basic electric furnace is slow and unsatisfactory since this removal is obtained only by contact of the slag with the metal in the bath.

Possibly the above summary may seem somewhat critical, but it is made so purposely in order to bring all the debatable points of the paper to light.

That basic open-hearth steel cannot be properly refined under normal operating conditions may seem rather a wide sweeping statement to open-hearth operators, but I shall leave it for them to discuss. There is no doubt, however, that a distinct advance in the art of steel making will result, if some auxiliary furnace or equipment can be obtained in connection with the open-hearth furnace that will produce economically a steel refined and deoxidized to the extent that is possible with the basic electric furnace when intelligently operated.

The author does not make any concrete suggestions as to the furnace equipment necessary in order to carry out the proposed operation. He does seem, however, to dismiss the basic electric furnace for the reason that it depends upon a calcium carbide slag for refinement necessitating contact of the bath with the slag during the refining period and hence offering a slow and unsatisfactory method of refinement. The electric furnace, however, really offers a more rapid refining rate than any other type of melting furnace excepting possibly the induction furnace. The basic electric furnace offers not only its peculiar and unique carbide slag for refinement, but also the method proposed by the author, i.e., the fluxing of the undesirable oxides in the bath by the addition of deoxidizers to form insoluble oxides which float out of the bath into the slag in a comparatively short time.

Not only does the basic electric process fulfill his first requirement but it also improves his second requirement,—that the oxides formed during refinement shall not flux FeO. Due to the reducing effect of the carbide slag any FeO that is fluxed and does come into contact with this slag is immediately reduced and the iron is returned to the bath as metallic iron.

Other recoverable metallic oxides may similarly be reduced from the

slag and delivered to the bath, thereby decreasing to a minimum the loss of alloys in the slag.

The basic electric furnace, therefore, does fulfill the requirements suggested by the author for correct refinement of steel.

Written Discussion: By Dr. R. H. Patch, E. F. Houghton and Co., Philadelphia.

Certain of the statements in Mr. Dornin's paper, while possibly true, are certainly misleading. For instance—he states at the bottom of page 61 "the total of iron oxide in the slag tends to constantly increase, due to the oxidizing effect of the furnace atmosphere on the FeO in the slag and it is not possible to reduce these iron oxides materially because anything that did this would also drive phosphorus back into the bath."

While it is undoubtedly true that the tendency of the iron oxide in the slag is to constantly increase, nevertheless, under proper operating conditions, it is possible to so manipulate the basic slag, that the percentage of iron oxide in the slag is reduced, and therefore obtain a slag which is less oxidizing in its nature, without driving phosphorus back into the bath.

In connection with the statement "we wind up with a bath full of gas and iron oxide," the writer believes it worth while stating that it is a known fact that a heat of steel, in condition for final additions is practically clean steel. It is the final additions, the tapping, pouring and pit conditions which frequently are the cause of the verdict "dirty steel."

In the second paragraph on page 63, Mr. Dornin states that "it is not possible to properly skim the slag off the bath." We believe that our experience with a basic electric furnace proves the contrary to this statement, for it is certainly done in hundreds of instances every day.

Mr. Dornin suggests the use of calcium carbide slag and states that "if the carbon and temperature be maintained, complete reduction of all oxides in the bath must eventually take place, provided the bath is so agitated that all parts of it come in contact with the slag."

It certainly would be interesting to have Mr. Dornin suggest some way in which it would be possible in a basic open-hearth furnace to so maintain conditions of carbon and temperature that there would be a reduction of all oxides in the bath, and particularly how the bath would be so agitated. We all know the extreme difficulty of proper agitation in the basic electric furnace, so that all parts of the bath come in contact with the slag. How it would be possible to so agitate an open-hearth bath when one considers that today the only means of agitation that we have is the "boil" from the oxides present in the bath, also demands some inkling as to how it is possible of practical attainment.

Finally, with regard to the conditions which may result after additions of silicon, manganese and aluminum to the bath and the warning that any insoluble oxides formed must not flux FeO, the writer fails to see how or why there is much need to worry on this account, providing the original conditions which Mr. Dornin set up of carbon and temperature are maintained. Because, obviously, under these conditions, it

would not be possible for these oxides to remain in the slag, neither for the FeO to be further oxidized by the flame, and thus build up.

Written Discussion: By H. M. German, metallurgist, Universal Steel Co., Bridgeville, Pa.

The old steel maker, who many years ago said "Take care of the slag and the steel will take care of itself," must have had the same thoughts as expressed in Mr. Dornin's paper. This old adage is as true today as when it was expressed, and is proven daily in the open-hearth and electric practices. A state of equilibrium never exists between the metal bath and the slag, and the migration of iron oxides may be from metal to slag or vice versa, depending upon the iron oxide contents of the metal and slag, temperature, carbon content of the metal and other conditions. Fortunately in the acid open-hearth and electric processes the operator has means to keep the amount of oxides in the slags below critical percentages and thus fix the direction of transfer from the bath to the slag and also means to render the oxides harmless after they enter the slag. The above transfer proceeds not only with iron oxides but also with the other metallic oxides, as manganese, aluminum, nickel, chromium, etc. The operator of a basic open-hearth furnace is at a disadvantage as the slag cannot be changed from oxidizing to reducing as phosphorus will be reduced and re-enter the metal.

In the acid open-hearth process, the slag at the end of the oreing period is dark brown in color and is heavily charged with iron oxides. The usual method of deoxidizing and clearing the slag is indirect, that is, by deoxidizing the metal with carbon and silicon, the equilibrium between the slag and metal is unbalanced and a migration of iron oxides occurs from the slag to the metal. As the transfer of oxides proceeds, the slag changes in color through successive shades of light brown, yellow and gray. If the charge is high in silicon and manganese the slags will change through a yellowish green to green color. The color of the slag may therefore be taken as an indication of the state of deoxidation of the bath. There is, however, a method for hastening the removal of oxides from the slag and causing the direction of migration of iron oxides from the metal to the slag. It consists of sprinkling a mixture of crushed bauxite and coke evenly over the slag after the action of the carbon is beginning to slow down. The aluminum in the bauxite replaces the iron and manganese oxides in the silicate slag and the carbon reduces them to their metallic forms and permits them to re-enter the metal. With this method there is no difficulty in producing a quiet, clean, light-colored slag, and the resulting metal will be of very high quality. The method can be applied to the acid electric practice as well as the acid open-hearth practice.

When melting with complete or partial oxidation in the basic electric furnace, the slag is removed after the oreing period. This is accomplished by tilting the furnace forward so that part will run out through the tapping spout, the remainder is removed by pushing it forward with bars and pulling it out with rakes. The slag is black in color and is

heavily charged with oxides and phosphates. A second or refining slag composed of limestone and feldspar is then made on the bath. When melted, this slag is dark in color due to oxides absorbed from the bath and furnace walls. Spreading carbon in the form of coke breeze or ground electrodes over the slag will change it to white or carbide, depending on the amount of carbon added. The direction of migration of oxides during the refining period is from metal to slag. As a carbide slag is strongly reducing, the oxides are reduced to their metallic form and are rendered harmless. When making low carbon steels and alloys and when a pick-up of carbon is dangerous, finely crushed ferrosilicon may be substituted for carbon to reduce the slag. From a quality standpoint, one of the greatest advantages of the basic electric furnace is the ability to maintain a reducing slag which greatly facilitates the deoxidation and degasification of the metal during the refining period.

A different condition exists in basic open-hearth practice, as the slag after oreing is not removed and replaced with a refining slag. An excess of limestone is added with the charge to effect the removal of phosphorus and sulphur and to maintain a basic slag at all times. When the charge is melted the slag is usually sluggish and contains lumps of lime. Increasing the furnace temperature will increase the solubility of the slag for lime and take the lumps into solution. In oreing care should be taken not to over-oxidize the bath. After oreing the slag is dark in color and heavily charged with oxides. Carbon cannot be added to clear the slag or phosphorus would be reduced and re-enter the metal. The action of carbon and silicon in the metal will deoxidize the bath and result in a migration of iron oxides from the slag to the metal. By carefully working the charge the content of iron oxides in both slag and metal can be reduced but the amount of elimination can never reach that attained in the previously described processes. Manganese also has the property of reducing calcium phosphate and if added in the furnace should be in the form of large lumps which will sink quickly through the slag. Final additions of recarburizers are made in the ladle. Whenever possible additions should be made in the furnace instead of in the ladle, as the steel will have a better opportunity to free itself of the solid products of deoxidation.

The basic open-hearth practice as suggested by Mr. Dornin to separate the metal and slag after the oreing operation and to finish under a reducing refining slag is feasible and would result in better quality steel but it is not clear how he proposes to separate the slag and metal. If the metal is drawn from under the slag, it will have to be refined in another furnace or held in a ladle until the slag is removed, and then pour it back into the furnace. A complete removal of slag after the metal is withdrawn is not possible. Refining in a second furnace would only be another form of duplexing. The logical way to remove the slag in a tilting furnace is to tilt the furnace sufficiently to permit most of the slag to run off and complete the removal as far as possible by working the slag to the spout with rods and pulling it out with rakes. Changes in furnace

design, particularly in the contour of the furnace bottom could be made to facilitate the removal of the slag.

Mr. Dornin is to be congratulated for his sincere efforts to improve the quality of basic open-hearth steel.

Written Discussion: By J. H. Flaherty, metallurgist, Jones & Laughlin Steel Corp., Pittsburgh.

Mr. Dornin's paper has pointed out that the weakness of present basic open-hearth steel-making lies in the fact that the slag and the bath at the end of a heat have become saturated with iron oxide. Also, that there is an equilibrium between the oxide content of the bath and the slag and that any efforts for complete refinement of the bath become futile because in the end a choice must be made between a steel carrying oxides in soluble form or a steel carrying the products of deoxidation. This because the time interval necessary for the products of deoxidation to eliminate themselves from the bath would permit saturation of the bath from the slag to be renewed. As a remedial measure he points to the possibilities that lie in the tilting furnace to reslag heats with some material which will reduce the iron oxide in the bath.

One of the best or perhaps the best index of the quality of a heat of steel in comparison with the quality of other heats of the same composition lies in the character of the surface of billets made from its ingots. If a heat is highly oxidized or is heavily charged with the products of deoxidation this condition will invariably be reflected in both billet rejections or scrap and the tons chipped per man day.

The iron oxide content of the slag of about forty heats of basic open-hearth 0.40 to 0.50 per cent carbon steel equivalent to forging quality were studied in connection with chipping data. Due to the interposition of other factors any direct-line relationship between the oxide content and the chipping was not evident. A division of the heats into two classes according to iron oxide content and a summation of the chipping data in each class indicates rather definitely, however, the effect of slag condition on the steel quality. The chipping rejections and tons per man of heats with less than 20 per cent iron oxide in the slag showed a considerable decrease in chipping rejections and a decided increase in the tons chipped per man day when compared with those showing over 20 per cent iron oxide in the slag. As the steel was all made and processed under the same practice and a sufficient number of heats is involved in the comparison fairly to assure the ironing out of other factors of difference between the two groups, we believe the figures are fairly indicative that the importance Mr. Dornin attaches to slag and oxidation conditions is fully justified not only from a final quality and service standpoint but also from the angle of possible saving in steel manufacturing costs.

We cannot subscribe to the author's view that the direction of improvement of present practice is toward double slags, rehandling of steel, etc. While we believe that for special purposes and to meet special conditions there may always be some desirability to double or triple slags, for operating cost reasons their application will be limited. For real

progress affecting the large tonnages of basic open-hearth steel we must rather look to developments from fundamental researches in deoxidation which correlate laboratory findings with actual plant practices and results. The work of C. H. Herty and his associates along such lines is typical.

Mr. Dornin is a past master at promoting thought and we foresee that his present effort will help to create the interest that it is his hope to build up in this very important subject of steel deoxidation.

Written Discussion: By D. F. McFarland, Head of Department of Metallurgy, Pennsylvania State College, State College, Pa.

Mr. Dornin's recommendations seem to be as follows,—

1. Use of a tilting furnace which permits removal of the oxidizing slag, high in iron oxides, which results from the working of the heat.

2. Covering the metal bath immediately with a ready-melted protecting slag, free from iron oxides, but of non-reducing character.

3. Reduction of the dissolved FeO in the bath by additions of silicon, manganese, and aluminum, with consequent mutual fluxing of the oxides formed, coalescence of the slag particles formed and removal to the slag blanket.

4. Prevention of the fluxing of the FeO by the other oxides formed.

In general, these suggestions commend themselves and the program seems worthy of study. Two or three items, however, require explanation,—

It is a little difficult to tell from the paper just how the separation of slag and metal is to be done. The natural thing would be to pour off the slag by tilting the furnace, although the paper seems to state the opposite. To "draw the bath from under the slag" would simply duplicate present practice with stationary furnaces, and would seem to necessitate carrying out the subsequent refining in another furnace.

Mr. Dornin does not state what he considers the best composition for the non-oxidizing, non-reducing slag. Even if this were initially free from iron oxide, it is likely that FeO would be formed by oxidation of the bath during the change of slags and would be a factor in the situation. This FeO and that already dissolved in the bath would be subject to reaction both with the deoxidizing agent, silicon, manganese, or aluminum, and with the oxides corresponding to these and it is difficult to see how the latter reactions can be avoided as is required in Mr. Dornin's last suggestion.

Written Discussion: By A. N. Conarroe, chief chemist, National Malleable & Steel Castings Co., Melrose Park, Ill.

Mr. Dornin's paper opens a subject which has had much discussion in the past. Modern engineering places greater demands upon the steel maker, since more strength with less weight seems to be the trend of the times. Greater strength for a given section is being accomplished by the addition of alloys, but many applications can be served as well with a cheaper grade of steel, when properly made.

As Mr. Dornin states, an unstable condition between the covering

slag and the metal results in reoxidation of the metal in the ladle. This proceeds to a greater or less degree according to the content of iron oxides in the slags. This fact leads him to the conclusion that all iron oxide should be reduced by means of deoxidizers after the removal of the oxidizing slag, leaving the covering slag neutral. From the standpoint of the removal of gas-forming elements Mr. Dornin's logic is correct. However, complete deoxidation involves the addition of a larger amount of silicon or aluminum, or both, which forms insoluble compounds which do not agglomerate readily and float out of the bath. This is particularly true of aluminum, which requires another base to help scavenge the bath if freedom from hard spots is to be assured. Silica also requires a basic oxide for its removal from the bath or glassy inclusions will result.

Herty has shown that small amounts of iron oxide assist in the elimination of silica from the bath. Thus the question of complete elimination of iron oxide is debatable.

One might draw the conclusion from Mr. Dornin's paper that no good steel is made under an oxidizing slag, yet, a large proportion of the steel today is made under these conditions and yields commercially sound material.

It should be borne in mind also that changes in practice leading to greater refinement place a greater burden upon the manufacturer and the additional cost involved must be absorbed by the price of the finished product.

Oral Discussion

C. H. HERTY, JR.:[a] There are just two points that I want to make. It would be easily possible to skim a slag from a small furnace, but it is a hard job from a big one, and for the people who suggest that the basic electric is what Mr. Dornin is looking for, I think they must keep that in mind. There is a big difference in trying to get a slag off a 20-ton furnace and a 200-ton furnace. In the second place, as far as the single furnace process is concerned, the double furnace process may be somewhat more expensive than the single furnace, but the added expense might be justified.

I know that in Europe there are four or five slags changed and that is either done in a single furnace or in a double furnace, or in some cases in three furnaces. In this country a higher cost along some lines makes it necessary to cut the number of furnaces, but I do think that we should be able to do something along these lines for certain grades of steel. One point that has been brought out is the fact that there are certain grades of steel where we really do not need all this extra refinement that we have spoken about. Certain grades of steel are just as good today as they will need to be ten years from now for certain definite purposes, and on that score I think all this discussion should be qualified, that there are grades of steel which we will be able to take care of with purely normal operation. In connection with the slag composition and the metal composition one of the discussers brought out the point that unless we know the iron oxide content of the metal we will

[a]Member A. S. S. T. Supervising metallurgist, metallurgical section, U. S. Bureau of Mines, Pittsburgh.

not be able to know how to add a deoxidizer, and that it was hard work to find what was the proper amount, or ratio, of deoxidizer. We hope we will soon have some very definite information on that. In the last two weeks we have gotten results from open-hearth operation which have revolutionized our ideas and it checks up very nicely with Mr. Flaherty's comments on the reductions due to the high iron oxide slag and the low. Now, whether to use high or low iron oxide is a proposition which depends on how the deoxidizer is used. At the present time we are trying to find out how to control that process.

CHAIRMAN RADCLYFFE FURNESS:[4] In taking up the question of slags as referred to in Mr. Dornin's paper I think we should recognize (whether this has been emphasized or not) that the changes that take place in a slag do not take place instantaneously. I think many have been carried away with the idea that if they have a slag in good condition the metal must be in good condition. That is not always true. It takes some little time for the slag to act, and again when the slag is put in perfect shape it takes some time for the flame to change that slag; in other words, in the acid open-hearth one can get white slag which will remain satisfactory for some time and will change but slowly and if, having obtained that slag, one treats the bath with proper reagents, one gets a much better steel than one is inclined to believe from the conversation and discussion that we hear now. The same applies to the basic furnace, although I never can feel that the basic furnace will produce as good material as the acid. Possibly that is prejudice. In fact, I am sure that I am prejudiced in favor of the acid furnace process on account of my long experience with that process in comparison with my short experience with the basic process.

As to the electric furnace, to me, it is a most wonderful tool. One can do things which simply seem impossible if he keeps his head about him. One can explain things which seem impossible to explain if one goes back and thinks of things he has done all the time throughout the past. As an example I will take the expression that one so frequently hears in connection with the furnace, that the heat was over-reduced. This generally means that after the ingots are cast they begin to swell. I do not think this phenomenon comes from one source. It can come from a dozen sources. The melting down may be done under such conditions as to make the heat swell at the end no matter what one does. The heat may be kept with certain alloys in it which increases its property to absorb gases and again that may cause it to swell, or in the fear that one will have a swelling heat due to absorbing reducing gases one runs the furnace a little bit on the oxidizing side and never gives it time to completely deoxidize. I probably talk about this because I have been bothered by this swelling in various alloys. I look to Mr. Batty and smile because I know from his paper that he must have had similar experience. I would like to hear whether he or any one else present believes that this so-called swelling is due to one cause or many causes as I believe.

GEORGE BATTY:[5] I believe that when Mr. Furness was discussing the swelling of steel in the molds he was referring to high chromium steel ingots, steel

[4]Member A. S. S. T. Superintendent of melting and forge departments, Midvale Co., Philadelphia.

[5]Member A. S. S. T. Research director, Steel Castings Development Bureau, Philadelphia.

of the stainless type. My recent experience, within the last five or six years, has been almost entirely with steel castings. There is something wrong with any heat of steel which has been subjected to the ordinary tests for soundness and condition by the furnace man—and which has successfully passed those tests,—that actually has a uniform rising condition in the molds. If such a steel gives swelling or rising in chilled molds it will most certainly give such a condition in a sand mold.

The over-reduced heats, as we know them, usually occurred when we had attained a high temperature in the furnace in making heats for light steel castings. The furnaces at Braintree in Essex were operating on a basic lining, but the walls and roofs were of acid material and the high temperature attained in endeavoring to promote the requisite degree of fluidity, as revealed by spoon tests, resulted in dripping and running of the silica refractories; hence we were getting a fair amount of silica into the basic slag. In these circumstances a heavy slag is inevitably built up so that we get considerable penetration of the slag by the electrodes. The contact of the carbon electrodes with the slag causes the reduction of silicon from the slag and, therefore, a silicon increment in the steel.

Melmoth holds, I believe, the opinion that silicon reduced to the metal from the slag imbues the steel either with an ability to absorb an unusual amount of gas, which gas it is unable to retain in solid solution, or, that the silicon reduced from the slag to the metal decreases the ability of that metal to retain in solid solution the gas which it held in solution while liquid. This postulates a difference in the behavior of silicon reduced from the slag as compared with silicon introduced as a ferro-alloy, and there have been in my experience many occurrences which would tend to confirm the assumption that this atomic silicon from the slag produces steel peculiar in its behavior as compared with steel in which the silicon addition is made as a ferro-alloy.

While I was with Melmoth in Essex we had several experiences of heats that rose in both dry sand molds and green sand molds. A spongy condition in steel castings, as a general rule, under modern conditions of furnace practice can be traced to gas injected into the metal from the molds, particularly from green sand molds of poor sand constitution, but it does seem conceivable that a little gas injected into steel which is slightly over-saturated may act physically on the metal and cause comparatively large amounts of gas to come out of solution which would otherwise have remained in solid solution.

With reference to the high chromium steels, I would draw a parallel with over-reduced heats of plain carbon steel and say that both these steels appear to present the phenomenal behavior of evolving a great deal of their surface heat as light. This theory of the evolution of surface heat as light was advanced by Dr. McCance many years ago at a lecture in Sheffield in particular reference to high chromium steels and to some high silicon steels, but at that time no mention was made of this peculiarity in reference to plain carbon steels for castings as produced in the electric furnace. There is, however, a similarity in the behavior of the high chromium steel and the over-reduced plain carbon electric steel in that both rapidly lose surface heat and film over when exposed to the atmosphere and that both are prone to unsoundness, sponginess,

swelling, or rising in the molds. In crucible practice I had no difficulty in obtaining sound ingots of the high chromium steels, but in the electric furnace trouble is undoubtedly frequently experienced.

G. A. DORNIN: I will answer most of the points in written discussion, but there are one or two things that I would like to bring out now. Mr. Fry, in his paper preferred acid steel, and I want to emphasize that acid steel under its present process can be made better than basic steel under its present process. The object of my paper is to try and bring about the change in the basic process which would eliminate that difference.

Replying to Dr. McFarland in regard to the slag composition, I have not a definite recommendation to make today, but I will refer you to a paper read by Federico O. Giolitti before the British Iron and Steel Institute in 1923 in which he took a basic heat, removed the first slag, diluted the slag a little, skimmed that off and then built a slag high in manganese oxide into which he introduced ferrosilicon and coke and built a residual manganese in the bath from 0.06 up to over 0.30 per cent. Silicon and chromium were added, and he wound up with a steel that was good enough for ball bearings and stood transverse tests. It was that paper that started the line of thought that has resulted in this paper.

Author's Reply to Written Discussion

In replying to Dr. Gillett, if we are to carry out our deoxidation under vacuum where CO will be removed from the bath as soon as formed, I will agree that we can use carbon as the initial deoxidizer. I will also agree that vacuum melting ought to be tried. I cannot, however, see where vacuum melting can play a material part in the making of any large percentage of the 40,000,000 tons of steel made in this country per year in the basic open-hearth furnaces.

If we are to deoxidize under atmospheric conditions, I do not think that we can use carbon as the initial deoxidizer because while its reaction product CO wants to get out it is my experience that it does not get out and it is my belief that our deoxidizers must not only reduce FeO but also CO or otherwise our ingots will be porous. As to the self-fluxing of the products of deoxidation being a hair trigger operation, I will agree that if we try to do this in a bath covered by an oxidizing slag as is the practice today in the basic open-hearth this is the case because FeO is constantly coming from the slag and changing the proportions of MnO and SiO_2 until there is too much SiO_2.

If, however, we do our deoxidizing under a non-oxidizing slag, I think we can control the relative proportions of MnO, SiO_2 and Al_2O_3 that we form in the bath within fairly close limits and certainly within limits where there will be self-fluxing. To do this MnO must be formed in the bath first and in sufficient quantity. Having MnO present in the bath, SiO_2 can be formed and the fusible manganese silicate ($MnO\text{-}SiO_2$) obtained which in its turn will flux Al_2O_3 if there is not too much Al_2O_3 and I do not think that there need be too much Al_2O_3 if we have no re-oxidation from the slag to contend with.

In reply to Mr. Elliott, I did not say that the finishing slag of the basic

open-hearth should be reducing. I do not believe that it needs to be reducing but only that it should be non-oxidizing. I should also have said that the finishing slag should carry no phosphorus. Such a slag can be maintained non-oxidizing for a considerable length of time by adding crushed ferrosilicon and coke. Any FeO getting into this slag, either by fluxing of the deoxidizers (SiO_2) or by diffusion from the bath, is reduced in the slag by these additions. Furthermore, if this finishing slag is high in MnO, manganese can be thus reduced from the slag and returned to the bath to deoxidize the bath. (See Giolitti, Iron and Steel Institute of Great Britain—1923).

I agree that a great deal of work is still necessary before this problem can be called settled, but I think the time has come to get at it and I think the detrimental effect of finishing heats under the highly oxidizing slag of our present day one-slag basic open-hearth process is the greatest cost load that steel making has to carry. I do not believe that the two-slag process will cost more than the present one-slag process, but less for the two phases of the process, oxidizing and refining, can then be carried out under favorable conditions instead of doing them as they are done today under conditions which are a compromise and suitable to neither.

In reply to Mr. Evans, I wish to make quite clear that I agree with him and with Mr. Furness that the basic electric furnace is a most wonderful tool. I believe that today it makes the highest quality steel made, and metallurgically I do not believe that we can improve on it as a process. When we stop to think, however, and realize that it has now been in use about twenty years and last year made only 5 per cent of the steel made in this country, there must be something lacking in it or it would have gone much further. The thing that is wrong with it, in my opinion, is its cost and I think, as I said in my paper, that its use will be limited to operations which can stand this cost and to certain others where its use saves valuable alloys in the scrap and under these latter conditions it is the cheapest process.

In replying to Dr. Patch, it is not possible to materially reduce the amount of iron oxides in a basic open-hearth slag carrying phosphorus. The percentage of iron oxides can be cut down if we increase the slag volume by adding more lime. The rate of diffusion of FeO is also slowed up by the thickening effect of this lime addition and this can also be helped by cooling the slag. When everything that can be done along these lines has been done, however, we still have a highly oxidizing slag and this slag interferes with and attempts to undo all of our subsequent efforts at refinement.

The bath at the end of the oxidizing phase is certainly full of gas and iron oxide. Any equilibrium diagram tells us this. It may be clean as far as silicates are concerned but it cannot be poured into molds in this condition and get anything but ingots that have blowholes and a high degree of segregation. Poured in this condition, it is commonly called open or rimmed steel.

In regard to skimming slags off the bath, I realize that this is the standard practice in the basic electric furnace. I still consider it an inefficient method for the following reasons: (1) It is slow. (2) It is very difficult to get all the slag except by cooling the slag down, which also slows the process. (3) It is essentially a hand operation and therefore costly. (4) I do not

think that the method of hand skimming that is simple enough on a 5-ton furnace could be carried out at all on a large 100-ton furnace or over.

I do not advocate the use of a reducing slag in the basic open-hearth process but of a non-oxidizing phosphorus-free slag for the finishing phase of the process. I also think the agitation of a bath is much less important where we are reducing FeO in the bath with deoxidizers and depending on colloidal action and flotation to give us clean steel, than where we are depending on a reducing slag.

In reply to Mr. German, I will refer him to my reply to Dr. Patch for the reasons why I consider skimming slag off a bath an inefficient method. I wish also to thank him for his addition to the paper in the excellent contribution to the metallurgy of slags contained in his discussion.

Mr. Flaherty's statement and data as to the direct effect on chipping costs and surface rejections of high iron oxides in the slag is a most gratifying proof that advice I have given for a number of years past has been good.

I cannot agree with him that the real progress in the future points to a one-slag basic open-hearth process better operated perhaps because of better understanding due to fundamental researches such as the work of C. H. Herty and his associates. To me all the lessons we have learned from research point inevitably to the future operation of the basic open-hearth as a two-slag process and to the impossibility of operating it as a one-slag process unless we are willing to continue to pay the penalty in losses and rejections due to this disobedience to fundamental metallurgical laws that are already well established. I believe that the cheap way to make steel is not to disobey fundamental metallurgical laws but to comply with them and in this paper I am pointing out where our present basic open-hearth process does not comply with them.

I have already answered Dr. McFarland's questions in my replies to the previous discussion.

To Mr. Conarroe, I will say that the work of Herty has shown that small amounts of iron oxide in the bath assist in the elimination of SiO_2. It has only shown this, however, when MnO was not present in the bath and if MnO is present, I do not believe we need the FeO to flux the SiO_2. Dr. Herty is now working on this phase of deoxidation and I think that his research when completed will sustain the above view.

I will ask Dr. Herty what grades of steel are just as good today as they will need to be ten years hence or even as good as the buyers and users think they should be today. Certainly not boiler plate made from rimmed ingots with the inevitable laminations that attend rimmed steel, certainly not rails with their present segregation, non-metallic inclusions, pipe and porosity, these being among the nuclei of transverse fissures, certainly not structural steel made largely from semi-killed ingots causing engineers to use factors of safety much higher than would be the case were the steel sounder, cleaner and more reliable.

No one places a higher value than I do on the research work of Dr. Herty but I cannot agree that our present day steel supply is satisfactory to its users except in very minor cases and small tonnages.

Mr. Furness has brought out that the reactions between slag and bath

do not take place instantaneously but that they require time. This fact is the one that makes deoxidation even partially possible in our present day one-slag basic open-hearth process. The reaction is, however, rapid enough to interfere with and prevent proper deoxidation. This same fact makes the use of a reducing slag to carry out deoxidation a slow and hence a costly process.

To Mr. Furness and Mr. Batty I will say that I believe the so-called over-reduction that they describe can take place only under a reducing slag. That it could not take place where a slag that was merely non-oxidizing was in use and the non-oxidizing slag seems to have this advantage over the reducing slag.

In closing, I wish to express my appreciation of and gratitude to all of those who have taken part in this discussion. Critical adverse discussion of a paper is frequently more valuable to the art and to the author than that which agrees with the author and I always welcome it and answer it so that both sides of the point at issue can be clearly brought out for study.

I have written this paper to point out a fundamental lack in our present day basic open-hearth process when operated with a single slag. I believe that the future of steel-making lies in a basic open-hearth process operated with more than one slag and that the tilting furnace is a necessary part of this process.

A MICROSCOPIC STUDY OF IMPROPERLY HEATED FORGINGS

By A. S. Jameson

Abstract

It is the purpose of this paper to illustrate a few of the defects which result from uncontrolled heating of steel prior to hot working or forging, and in doing this show how valuable a tool the microscope is in determining the exact occurrence of these flaws.

IN the majority of plants insufficient attention is paid to the heating of the steel with regard to its internal structural changes which are so clearly revealed by the microscope. The result of this omission is a high scrap loss and inferior forgings. Temperature and time are inseparable partners in correct heating. A few cases will illustrate how temperature and time have had slight consideration in the production of forgings. It is convenient to divide the subject under the following headings:

(1) Overheating and its effect in the forging process
(2) Overheating and its effect on the physical properties of the steel
(3) Too rapid heating
(4) Underheating.

Overheating and Its Effect in the Forging Process

When determining the correct forging temperature the carbon content of the steel is the important factor to be considered. As the carbon content increases the more "tender" the steel becomes.

Overheating of low carbon steel. Though low carbon steel is difficult to overheat, the steel does lose its plasticity at high temperatures and is torn apart by the forging dies. An example of this is shown in Fig. 1. This is a roller bearing race, having deep cracks running around the circumference. On examination this race shows evidences of extremely high forging temperatures. The material is S.A.E. 1015 steel containing 0.17 per cent carbon, 0.49 per cent manganese, 0.021 per cent sulphur and 0.010 per cent phosphorus.

The author, A. S. Jameson, a member of the society, is metallurgist, West Pullman Works, International Harvester Co., Chicago. Manuscript received May 23, 1929.

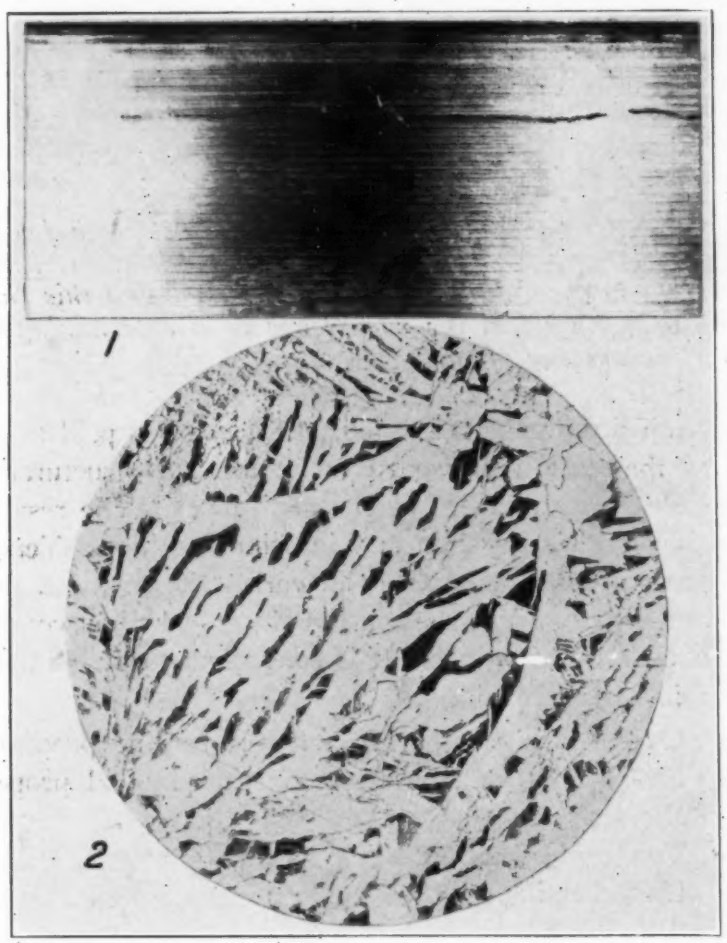


Fig. 1—Deep Crack in Bearing Race Caused by Crystal Rupture in Forging Die.
Fig. 2—Overheated Low Carbon Steel. × 100.

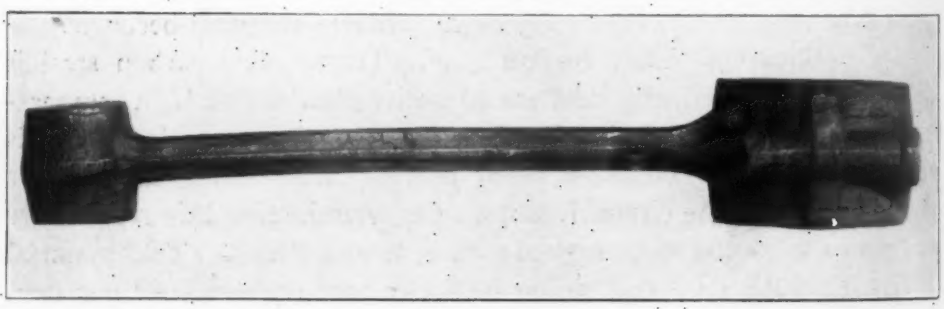


Fig. 3—Surface Cracks on a Connecting Rod Forging. Etched in 50 Per Cent HCl.

Upon examination under the microscope the steel was found to be clean and free from slag inclusions. Upon etching with a solution

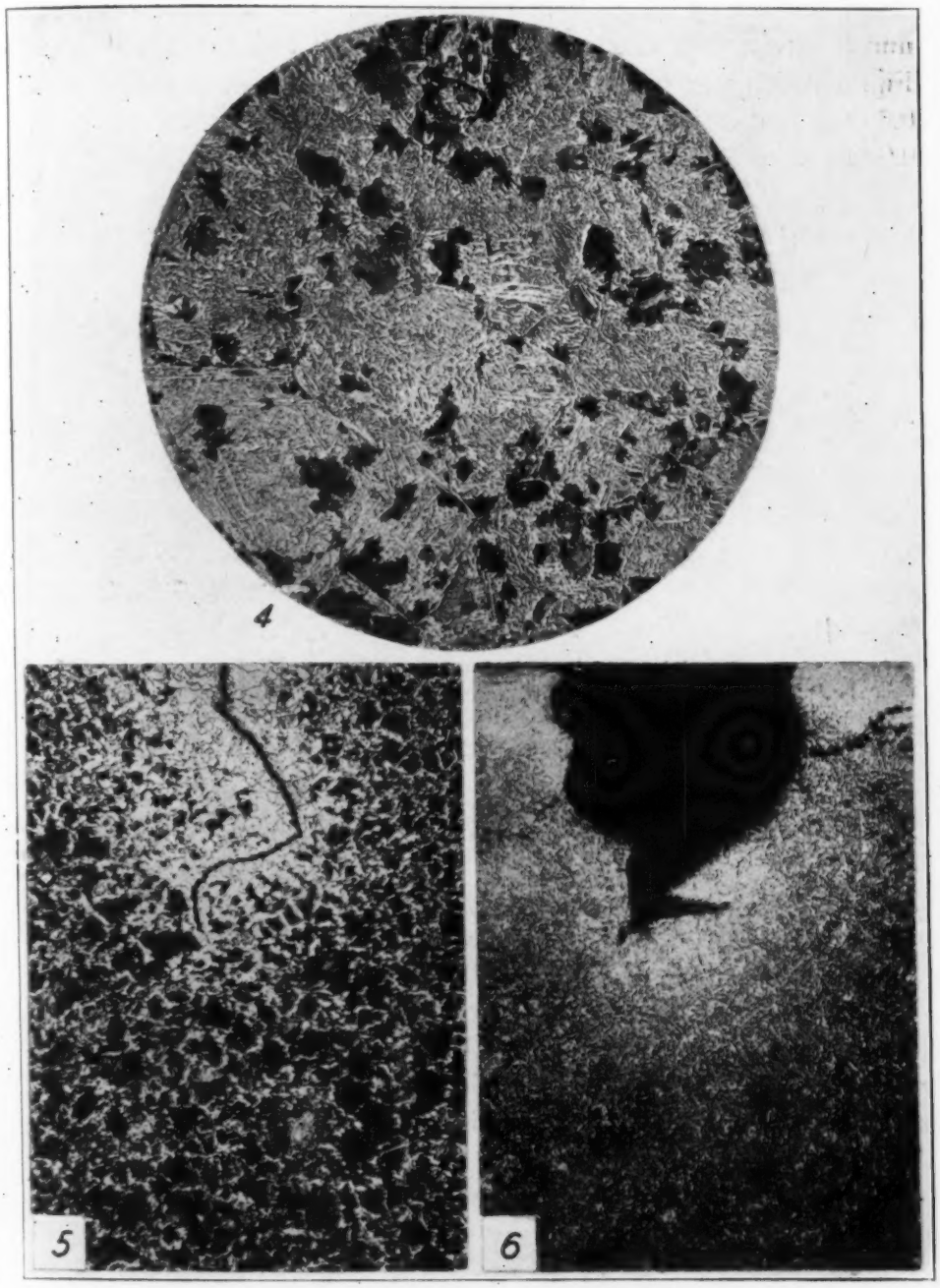


Fig. 4—Overheated Structure of "As-Forged" Connecting Rod. × 100.
Fig. 5—Normalized Structure of Connecting Rod Forging Showing Decarburization at Crack. × 100.
Fig. 6—Quenched and Tempered Structure of Connecting Rod Forging Showing Decarburization at Crack. × 100.

of 2 per cent nitric acid in alchohol, a typical overheated structure was observed as shown in Fig. 2.

Overheating of medium carbon steel. Overheating resulted in numerous surface cracks on the connecting rod forging shown in Fig. 3 which was fabricated from a pearlitic manganese steel having 0.39 per cent carbon, 1.73 per cent manganese, 0.025 per cent sulphur, 0.020 per cent phosphorus and 0.15 per cent silicon. Figs. 4, 5 and

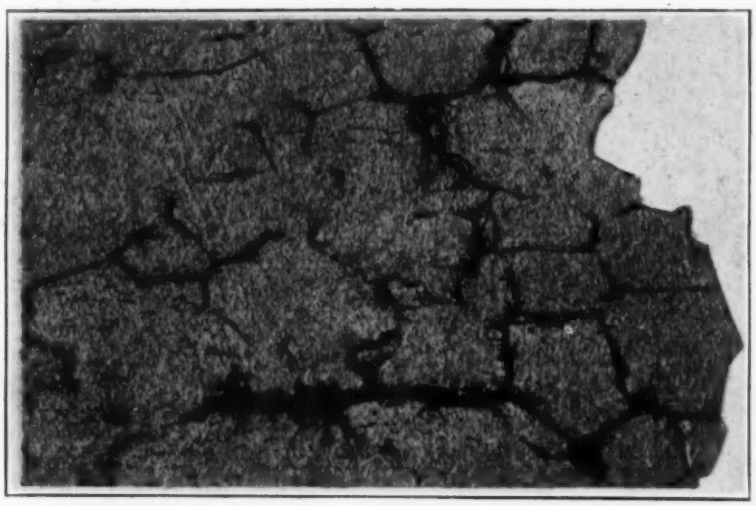


Fig. 7—Surface of a Section of a Burned Billet Overheated in Forging.

6 show the structure of this forging "as-forged" and also after normalizing and heat treating. Figs. 5 and 6 show decarburization at the crack.

Fig. 7 is a photograph of a billet of S.A.E. 1040 steel which was to be used in a rear axle forging. In this case the cohesion between the crystals is destroyed and steel is said to be burnt. The billet was so badly burnt that it crumbled under the hammer. The photomicrograph, Fig. 8, shows that the grain boundaries are surrounded by brittle membranes. The steel was normalized and the small grain size was restored but the cracks remain (Fig. 9).

Overheating of high carbon steel. Steels of eutectoid and hypereutectoid composition are very susceptible to overheating. A leaf spring of S.A.E. 1090 steel was found to be extremely brittle. On examination under the microscope it was seen that the steel had been burnt in the forging operation. (Fig. 10).

Overheating and Its Effect on the Physical Properties of the Steel

Overheating is of great importance where the steel is used in

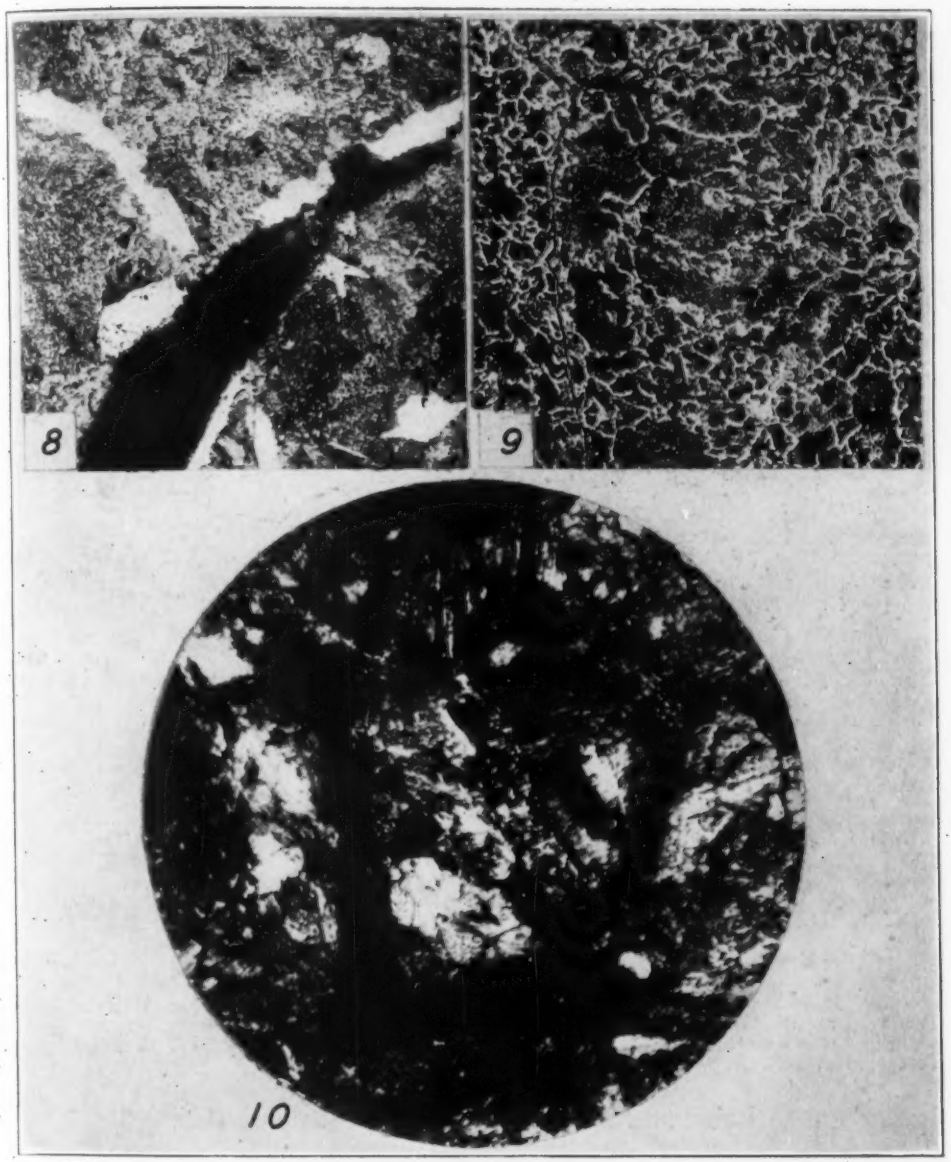


Fig. 8—Brittle Membranes Surrounding Grain Boundaries of Burned Medium Carbon Steel. × 100.

Fig. 9—After Normalizing Specimen of Fig. 8 the Small Grain Size was Restored but the Cracks Remain. × 100.

Fig. 10—Structure of Burned High Carbon Steel Damaged in the Forging Operation.

the "as-forged" condition. It is rare, however, that in the automotive industry the steels are used in the "as-forged" state.

The following average properties obtained on 6-inch rounds of the analysis: carbon 0.36 per cent, manganese 1.75 per cent, in the "as-forged" condition compared with the same forgings reheated to

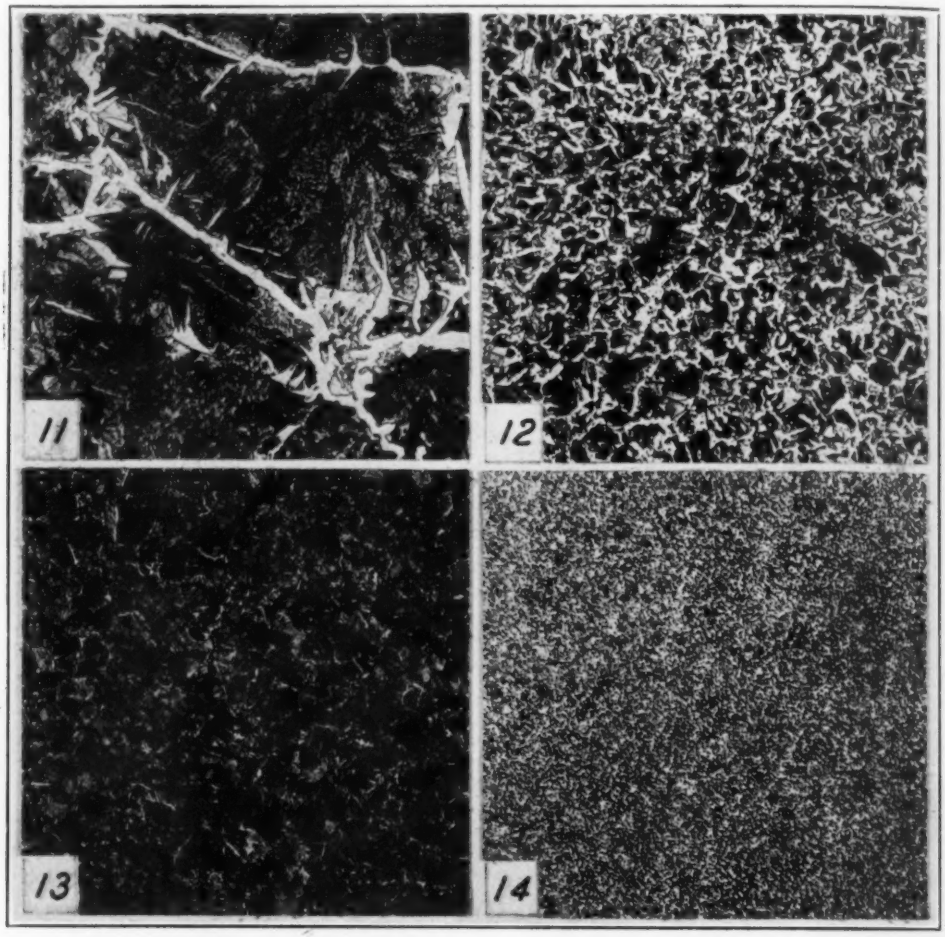


Fig. 11—Structure of Medium Carbon Steel "As-Forged." × 100.
Fig. 12—Structure of Fig. 11 after Normalizing at 1600 Degrees Fahr. × 100.
Fig. 13—Structure of Fig. 11 after Quenching in Water from 1525 Degrees Fahr. Tempered at 1000 Degrees Fahr. Shows Incomplete Refinement. × 100.
Fig. 14—Structure of Fig. 12 after Quenching in Water from 1525 Degrees Fahr. Tempered at 1000 Degrees Fahr. Fine Sorbite. × 100.

1550 degrees Fahr. and air-cooled serve to illustrate this.

Treatment	Yield Point Pounds per Square Inch	Ultimate Strength Pounds per Square Inch	Elongation in 2 Inches	Reduction of Area Per Cent.
"as-forged"	80,710	108,920	5.2	3.6
N-1550 degrees Fahr.	70,180	107,750	22.3	42.8

Effect of high forging temperatures on subsequent heat treatment. It is shown by the following series of physical tests and photomicrographs the importance of a controlled forging temperature if one desires to produce a quality product with the most economical heat treatment.

Connecting rods of S.A.E. 1040 steel showed improved proper-

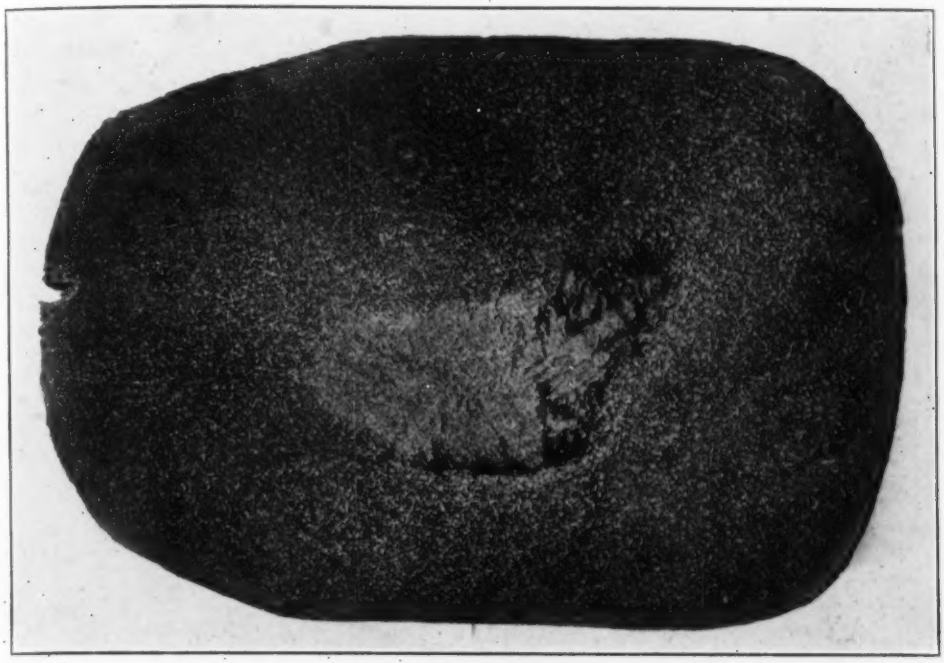


Fig. 15—Cross Section of an Automobile Front Axle Burst in Forging.

ties when normalized previous to heat treatment. The rods were quenched from 1525 degrees Fahr. in water and tempered at 1000 degrees Fahr. Their physical properties are as follows:

Laboratory No.	Yield Point Pounds Per Square Inch	Ultimate Strength Pounds Per Square Inch	Elongation in 4 Inches	Brinell Number	Carbon Per Cent
A-1	83,800	102,200	11.8	255	0.38
A-2	83,800	106,400	9.8	248	
A-3	85,400	107,500	10.6	255	

When air-cooled from 1600 degrees Fahr., after holding for 1 hour, and reheated and quenched from 1525 degrees Fahr., holding 30 minutes, they were tempered at 1000 degrees Fahr., and showed the following physical properties:

Laboratory No.	Yield Point Pounds Per Square Inch	Ultimate Strength Pounds Per Square Inch	Elongation in 4 Inches	Brinell Number	Carbon Per Cent
B-1	94,400	110,800	10.8	255	0.40
B-2	96,500	110,500	10.6	255	
B-3	95,500	109,800	11.7	255	

Examination of the rods at various locations made it clear that those which did not receive the normalizing treatment had a structure showing incomplete refinement (Fig. 13). The structures obtained after these treatments are shown in Figs. 11 to 14.

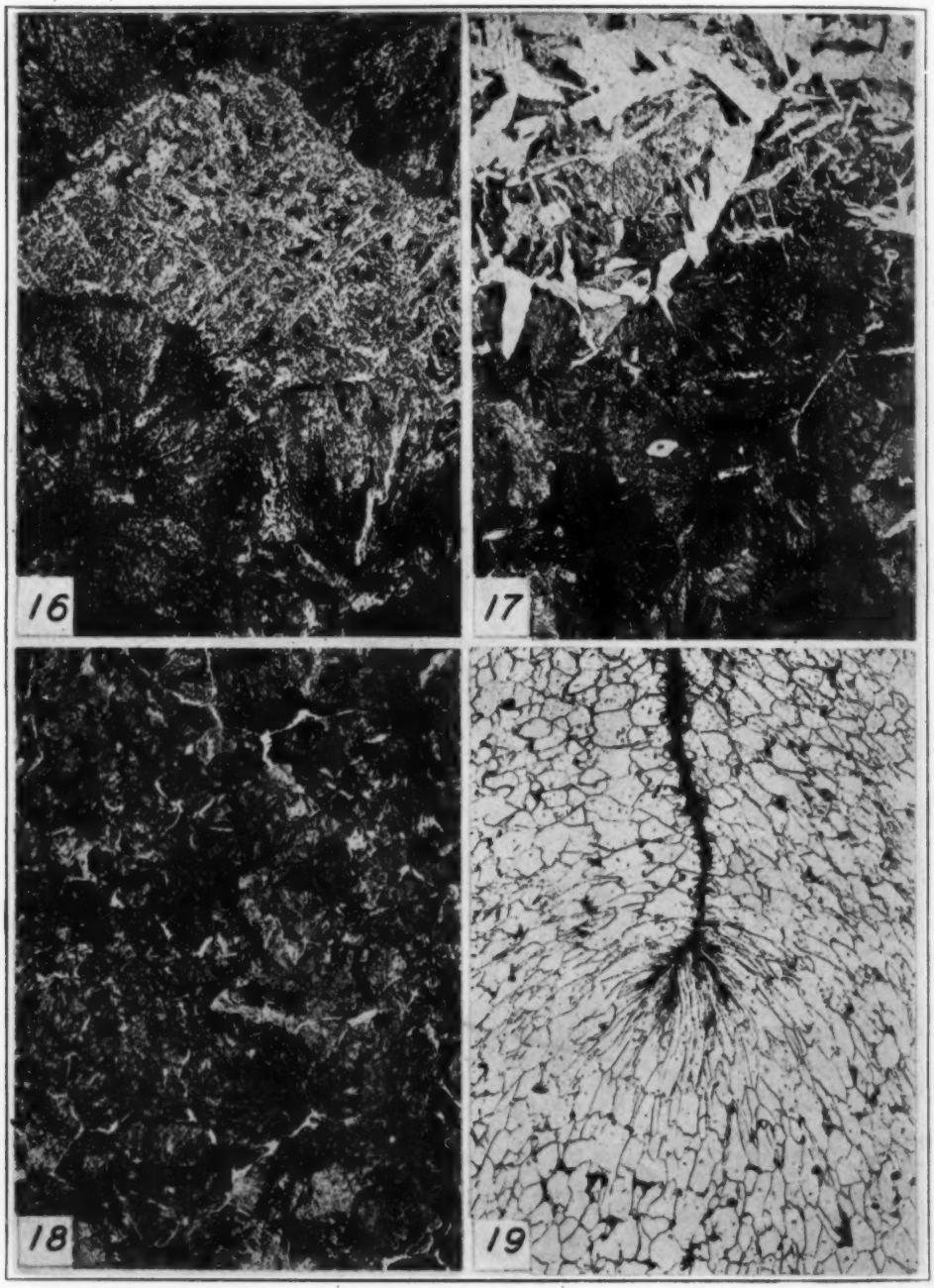


Fig. 16—Structure Resulting from Heating too Rapidly to a High Temperature. Overheated Steel. × 100.

Fig. 17—Same as Fig. 16 Showing Decarburized Surface and Coarse Grain Size. × 100.

Fig. 18—Specimen Same as Fig. 16 after Heat Treatment. This Specimen Indicates Poor Soaking at Hardening Temperature. × 100.

Fig. 19—Structure of Low Carbon Steel which has been Forged at too Low a Temperature Resulting in the Distortion of the Grains by Cold Work. × 100.

Fig. 20—Photomicrograph Showing Neumann Lines. × 500.

Too Rapid Heating

Heating too rapidly generally results in work being done on a billet which is not at a uniform temperature throughout. Fig. 15 is a front axle forging of S.A.E. 3140 steel with a large internal burst, a condition entirely due to attempting to forge a billet which had not been allowed to soak for a sufficient length of time. The billet had been charged into a hot furnace and rapidly heated.

Billets from the same forging heat of steel had a coarse grain structure (Fig. 16) and a decarburized surface (Fig. 17), indicative of too rapid heating to a high temperature. Fig. 18 has a structure which indicates poor soaking and incomplete solution ferrite with a non-uniform grain size.

Underheating

The underheating of forgings is not uncommon, at least certain areas, corners on thin sections, are placed under the hammer at temperatures under the critical range.

This may often be detected by the elongation of the ferrite crystals (Fig. 19), and in rarer instances by the presence of Neumann lines (Fig. 20) which are twinned crystals produced by mechanical straining. If the distortion is carried to an extreme it will lead to loss of ductility and finally rupture of the forging.

INHERENT HARDENABILITY CHARACTERISTICS OF TOOL STEEL

By B. F. Shepherd

Abstract

This paper discusses variations in hardening properties encountered in carbon tool steels; pointing out that among steels of practically identical composition, wide variations in depth of hardness penetration are possible. It shows, by the use of a special test, the magnitude of these variations between heats from the same manufacturer and between different manufacturers.

Foreword

An ultimate chemical analysis of human bodies from various parts of the world would show very little difference in actual composition. The difference in mental and physical characteristics, however, is very great. Each race has certain features characterizing its habits of thought and action and often in individual families we find strikingly similar mannerisms. Heredity and training have their influence in producing these racial and family traits. In the same manner, heats of steel differ from or are similar to each other in their characteristics. The difference between a particular specification is more or less marked in material from different mills, depending upon the care and attention given to the manufacture.

An ultimate chemical analysis of steel from various manufacturers shows little difference between heats of the same type composition. Specifications have been adopted by many of the national engineering societies limiting the range of chemical composition in various types of steel. Individual metallurgists have adopted special inspection methods, to determine differences in quality in the product of different manufacturers as expressed by freedom from inclusions, ability to meet certain physical tests, etc. Steels may meet all of these specifications, inspection tests, etc., and still fail to perform satisfactorily in service.

It is well known that different heats of steel from the same

A paper presented before the Eleventh Annual Convention of the Society, Cleveland, September 9 to 13, 1929. The author, B. F. Shepherd, member of the society, is metallurgist with the Ingersoll-Rand Co., Phillipsburg, N. J. Manuscript received July 8, 1929.

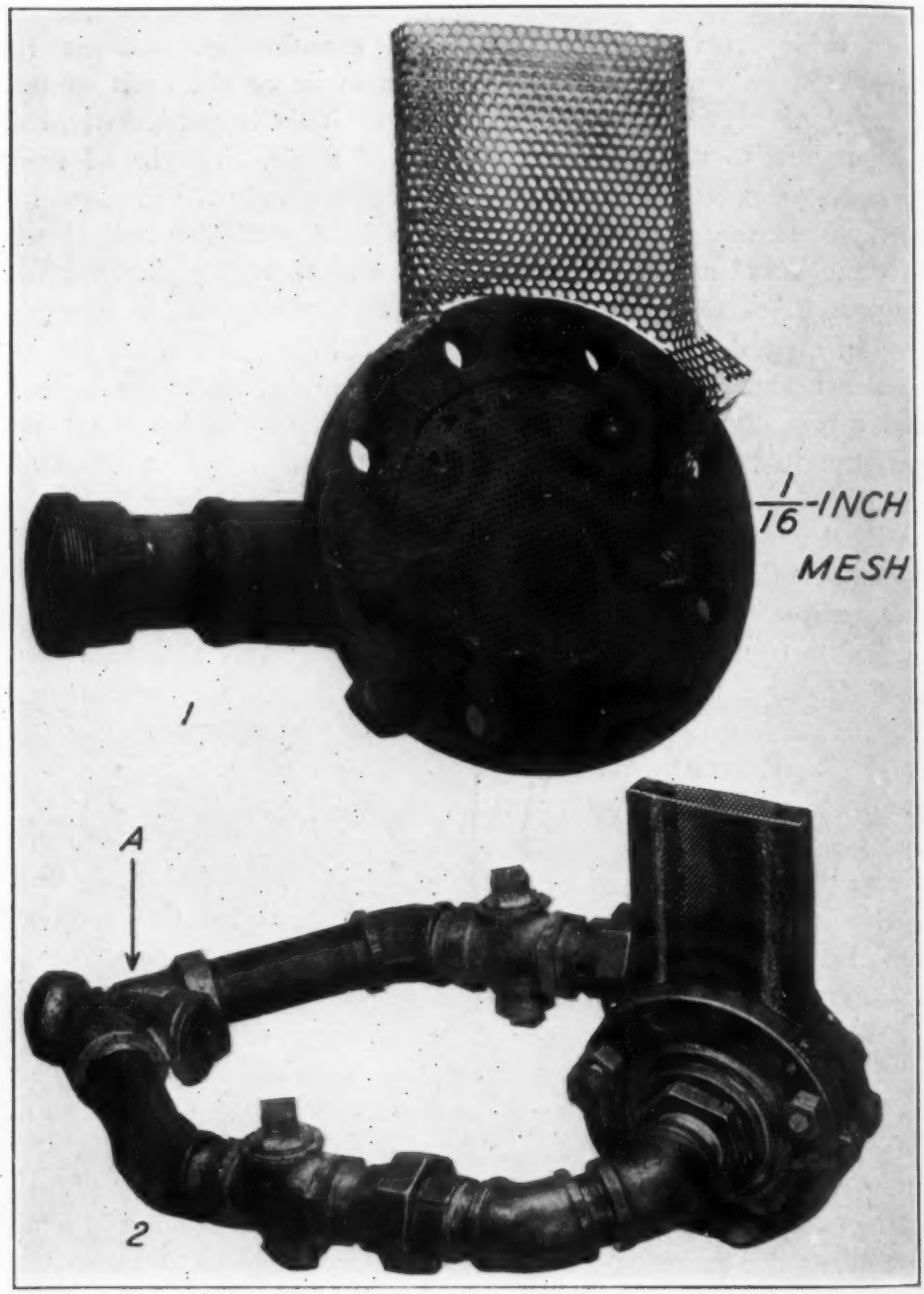
manufacturer often show individual characteristics which are unexplainable on the basis of chemical examination. Claims for superiority of certain brands have been made on the basis of uniformity of obtained physical properties. This is particularly true with regard to tool steel and high speed steels. The brand name on these products is supposed to designate not only the product, but to represent the particular quality made by a particular mill. Many of these brand names are still well known and widely used for this purpose.

In early days the brand name indicated the composition to such an extent that the actual analysis was surrounded with much secrecy and rarely divulged. The eventual reaction caused too much importance to be placed upon chemical analysis. Specifications were made upon this basis and tool steels were considered interchangeable on the basis of similarity of chemical analysis. The quality of the steel as indicated by the ability to withstand service requirements was assumed to be a common characteristic of steels of the same analysis. Consideration was not given to the fact that equivalent analysis did not make two steels equal in quality and interchangeable. The use of the term "body" came to be associated with the old days of steel manufacturing, when steel makers did not have the openness of mind which exists at the present time. The idea that steel could have an unknown inherent quality which would give it superiority was thought an ancient idea. The "body" obtained in Sheffield steels by the use of Swedish iron and quality wrought into the material by the skill of the melters was thought merely a "sales idea" for this type of steel.

It is the intention of this paper to show data obtained by a special hardening test which indicate that an inherent condition does exist in tool steel which has a great influence upon the hardening characteristics or hardenability, this term being used for want of a better name. The data are shown for simplicity as a series of separate experiments which are intimately related. No attempt is made to explain the cause of this inherent difference in hardenability as this is distinctly connected with the pre-natal history of the material.

Hardenability Test Method

The hardenability of the steel was determined by quenching slabs of varying thickness in a special spray. These were cut in



Figs. 1 and 2—Showing Assembled and Interior View of Quenching Spray.

half with a $\frac{1}{16}$-inch elastic grinding wheel and etched to show depth of hardening. Two variations were made of this test depending upon diameter of the bar stock. Where this was less than $3\frac{3}{8}$ inches separate slabs were used for each thickness. Where the di-

ameter was 3⅜ inches or larger, three steps were ground on each slab. The center step was 1¼ inches wide which gave sufficient width for each section to assume its particular quenching speed. The thickness was controlled to 0.001 inch plus or minus. The hardenability is reported as the number of 32nds in the thinnest section which does not harden through.

Heating Operation

The heating was done in approximately 20 minutes in an automatically controlled electric lead pot, with a thermocouple inside the pot. The slabs were not preheated. A record chart was made of the heating operation and all tests were run with duplicate slabs which were hardened from separate heats.

Quenching Operation

After many experiments, it was found that the most effective spray was a simple one, made from 2-inch pipe and pipe flanges as shown in Figs. 1 and 2. This spray was used with a brine tank and circulation provided by a Cameron No. 2LV centrifugal pump motor driven at 720 revolutions per minute. This supplies a pressure of about 4 pounds at A (see Fig. 1) when valves are open full. The brine is about 35 salometer and 75 degrees Fahr. The screen guide permits slabs to be inserted without preliminary splashing.

Hardening Range Determination

A wide range of sizes was used for the determination of the range of hardenability. For straight carbon tool steel this had been adopted as $\frac{9}{32}$, $\frac{5}{16}$, $\frac{11}{32}$, $\frac{3}{8}$, $\frac{13}{32}$ and $\frac{7}{16}$ inch. For sizes 3⅜ inches and over, one slab was used for the first three and one for the last three thickness. After this preliminary determination control inspection may be made on a much smaller range of thicknesses.

Hardenability—MFG. X

Ten heats of 1.05 to 1.15 per cent plain carbon tool steel were tested for hardenability range on slabs taken from billets. Slabs were first oil-treated from 1600 degrees Fahr. (870 degrees Cent). and then hardened from 1440 degrees Fahr. (780 degrees Cent.). The analysis and hardenability of this group of steels is shown in Table I and the etched tests of the specimens are shown in Fig. 3.

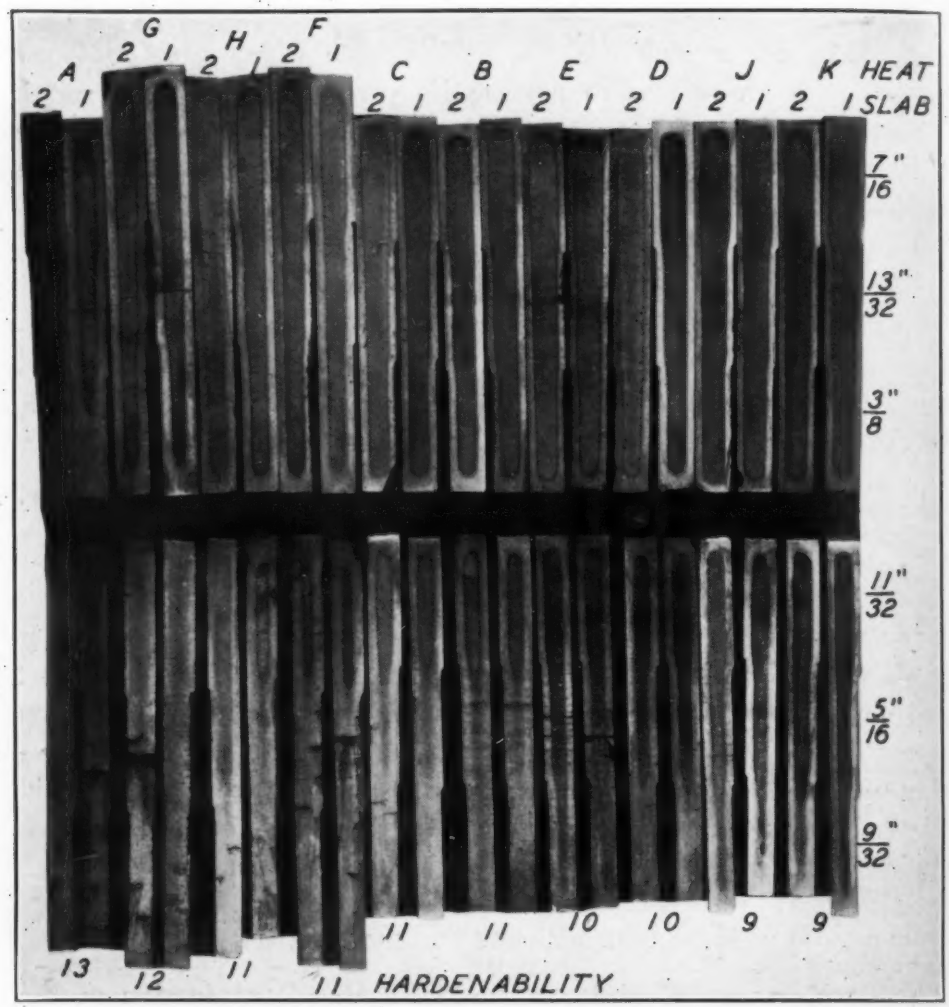


Fig. 3—Showing Variation in Hardenability of Ten Heats Listed in Table I. 4-inch Billets, 1.05 to 1.15 Per Cent Carbon. Mfg. X.

Table I

MFG X. Hardenability Tests and Chemical Composition of Steels

Lab. No.	Heat No.	Size	C	Mn	P	S	Si	Cr	Ni	Hardenability
K	JX4006	4 " sq.	1.16	0.26	0.012	0.024	0.23	0.01	0.03	9
J	JX4002	4 " sq.	1.15	0.25	0.010	0.019	0.16	0.01	0.03	9
D	HX4384	4 " sq.	1.05	0.22	0.020	0.023	0.22	None	0.01	10
E	HX4406	4 " sq.	1.13	0.27	0.014	0.020	0.22	0.02	0.02	10
B	HX4343	4 " sq.	1.09	0.26	0.011	0.017	0.19	0.06	0.02	11
C	HX4349	4 " sq.	1.05	0.26	0.010	0.020	0.21	0.02	None	11
F	JX4291	4½" sq.	1.04	0.29	0.010	0.018	0.17	0.05	0.01	11
H	JX4300	4½" sq.	1.08	0.25	0.012	0.017	0.16	0.05	None	11
G	JX4292	4½" sq.	1.05	0.24	0.016	0.022	0.18	0.05	0.01	12
A	HX4209	5 " sq.	1.15	0.30	0.014	0.015	0.42	None	0.05	13

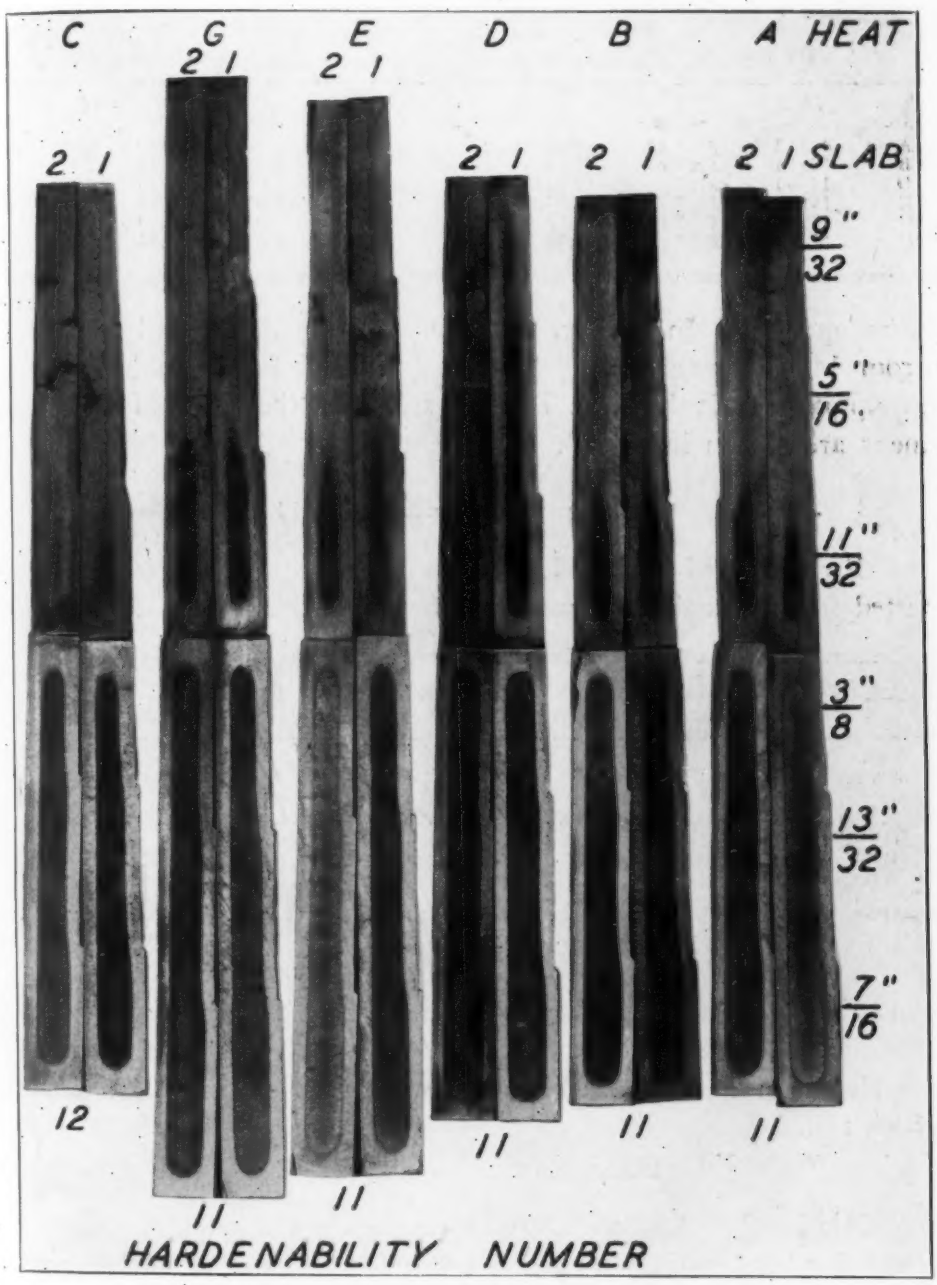


Fig. 4—Showing Variation in Hardenability of Six Heats Listed in Table II. 3¼ to 4-inch Round Bars, 1.00 to 1.10 Per Cent Carbon. Mfg. Y.

HARDENABILITY—MFG. Y

Six heats of 1.00 to 1.10 per cent plain carbon tool steel were tested for hardenability range on slabs taken from bars. Slabs

Table II
MFG Y. Hardenability Tests and Chemical Composition of Steels

Lab. No.	Heat No.	Size	C	Mn	P	S	Si	Hardenability No.
A	14762	3¼" rd.	1.06	0.24	0.009	0.020	0.18	11
B	14918	3¼" rd.	1.08	0.26	0.014	0.019	0.24	11
D	14760	3⅜"	1.04	0.23	0.019	0.019	0.16	11
E	14809	3⅞"	1.00	0.24	0.011	0.018	0.24	11
G	14517	4 " rd.	1.07	0.28	0.012	0.015	0.19	11
C	14894	3¼" rd.	1.01	0.28	0.015	0.018	0.24	12

were quenched in oil from 1600 degrees Fahr. and hardened from 1440 degrees Fahr. The analysis and hardenability of this group of steels is shown in Table II and the etched tests of the specimens are shown in Fig. 4.

Hardenability—MFG. U

Five heats of 1.10 to 1.15 per cent plain carbon tool steel were tested for hardenability range on slabs taken from bars. Slabs were

Table III
MFG U. Hardenability Tests and Chemical Composition of Steels

Lab. No.	Heat No.	Size	C	Mn	P	S	Si	Cr	Ni	Hardenability
D	E-2029	3¼" rd.	1.17	0.19	0.019	0.017	0.20	0.06	Nil	11
A	E-2587	3⅛" rd.	1.10	0.25	0.018	0.015	0.19	0.10	0.07	12
C	E-2396	3½" rd.	1.17	0.27	0.018	0.017	0.24	0.08	0.07	12
E	E-2231	4¼" rd.	1.14	0.25	0.019	0.016	0.17	0.06	Trace	12
B	E-2559	3¼" rd.	1.11	0.21	0.018	0.015	0.22	0.09	0.04	13

quenched in oil from 1520 degrees Fahr. and hardened from 1440 degrees Fahr. The analysis and hardenability of this group of steels is shown in Table III and the etched tests of the specimens are shown in Fig. 5. A third slab was taken on Lab. No. C as a check test.

Hardenability—MFG. W

One heat of 1.00 to 1.10 per cent plain carbon tool steel was tested for hardenability on a slab taken from a bar. The slabs were oil-treated from 1520 degrees Fahr. One set was hardened from 1420 degrees Fahr., the other set (same size) from 1440 degrees Fahr. The analysis and hardenability of this steel is as follows:

Lab. No.	Heat No.	Size	C	Mn	Si	Hardenability No.
Z	947	2⅜" rd.	1.01	0.26	0.14	10

The etched tests of the specimens are shown in Fig. 6.

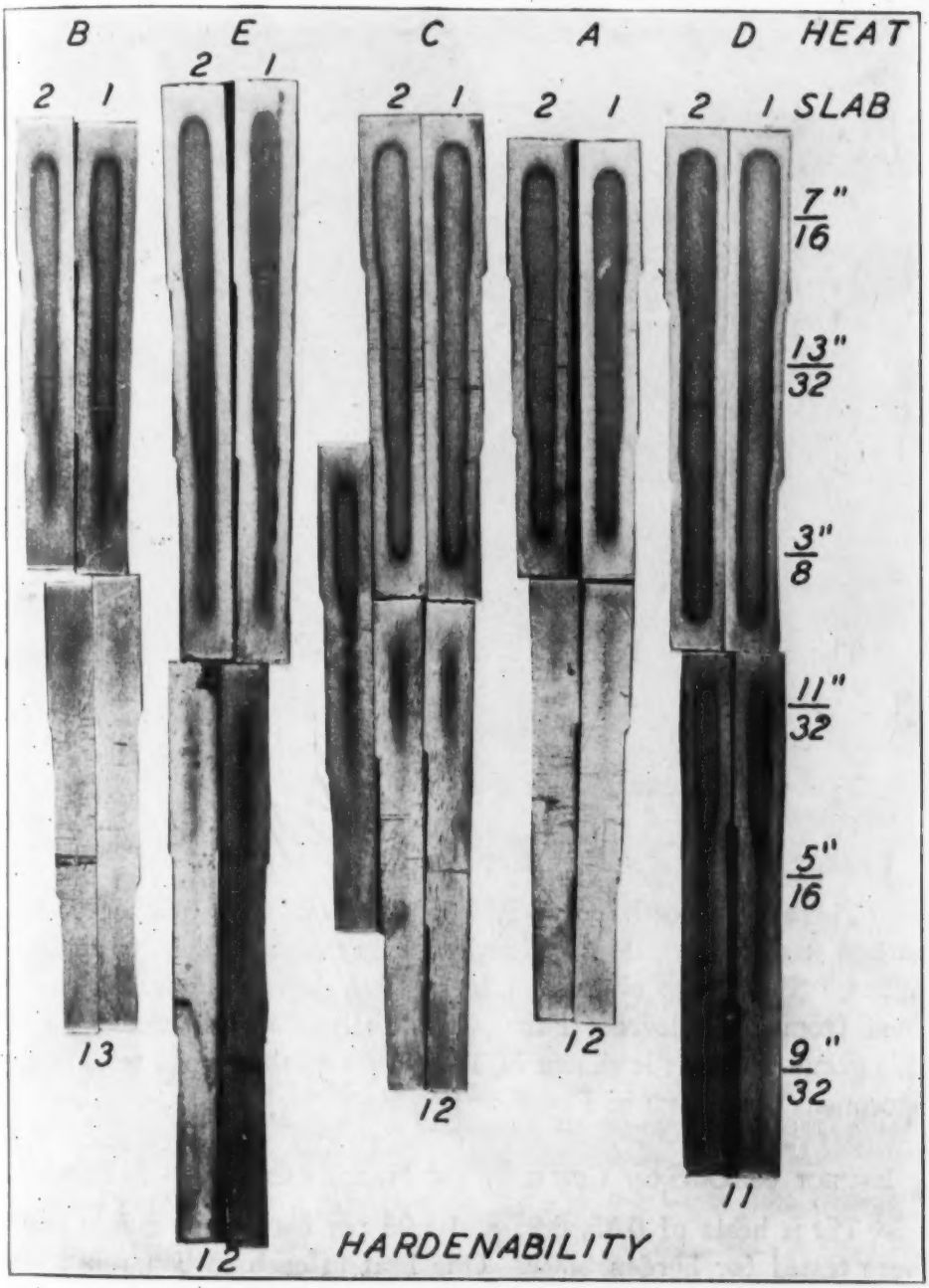


Fig. 5—Showing Variation in Hardenability of Five Heats Listed in Table III. 3⅛ to 4¼-inch Round Bars, 1.10 to 1.15 Per Cent Carbon. Mfg. U.

Hardenability—MFG. T

One heat of 1.00 to 1.10 per cent plain carbon tool steel was tested for hardenability on slabs taken from a bar. The slabs were

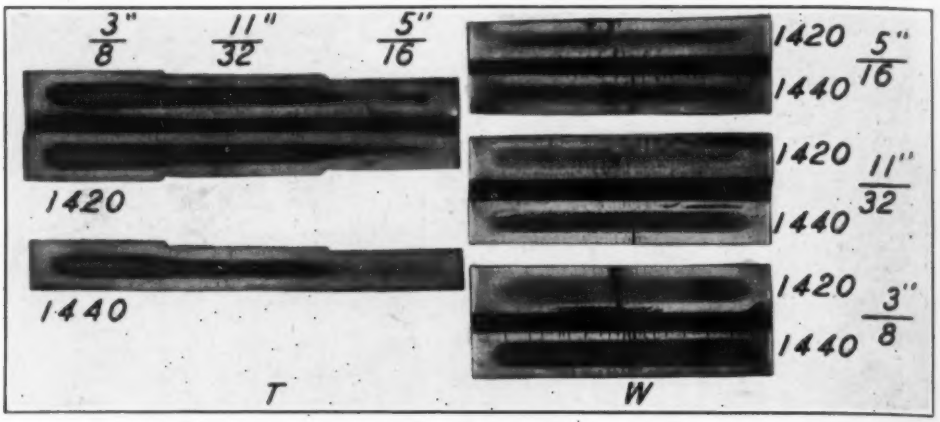


Fig. 6—Showing Variation in Hardenability of One Heat from Mfg. W and One Heat from Mfg. T. 1.01 to 1.03 Per Cent Carbon Steel.

oil-treated from 1520 degrees Fahr. One slab was hardened from 1440 degrees Fahr. Two slabs were hardened from 1420 degrees Fahr.

The analysis and hardenability of this series is as follows:

Lab. No.	Heat No.	Size	C	Mn	P	S	Si	Cr	Hardenability No.
B	2126	3⅛" rd.	1.03	0.21	0.028	0.010	0.15	0.01	11

The etched tests of the specimens are shown in Fig. 6.

Effect of Carbon Content on Hardenability— MFG. Z

Three heats each of 0.75, 0.85, 0.95 and 1.05 per cent plain carbon steels were tested for hardenability range on slabs taken from billets. Slabs were oil-treated from 1600 degrees Fahr. and hardened from 1440 degrees Fahr. The analysis and hardenability of this group of steels is shown in Table IV and the etched tests of the specimens are shown in Fig. 7.

Effect of Carbon Content on Hardenability— MFG. V

Three heats of 0.85, 0.95 and 1.05 per cent plain carbon steels were tested for hardenability. One heat in each carbon range was supposed to be shallow, another medium and the other a deep hardening steel, made intentionally with this feature in mind. The range of sizes was altered accordingly. After the first tests additional slabs were taken to supplement the previous tests. All slabs were oil-treated from 1520 degrees Fahr. and hardened from 1440 degrees Fahr. The analysis and hardenability of this series of steels

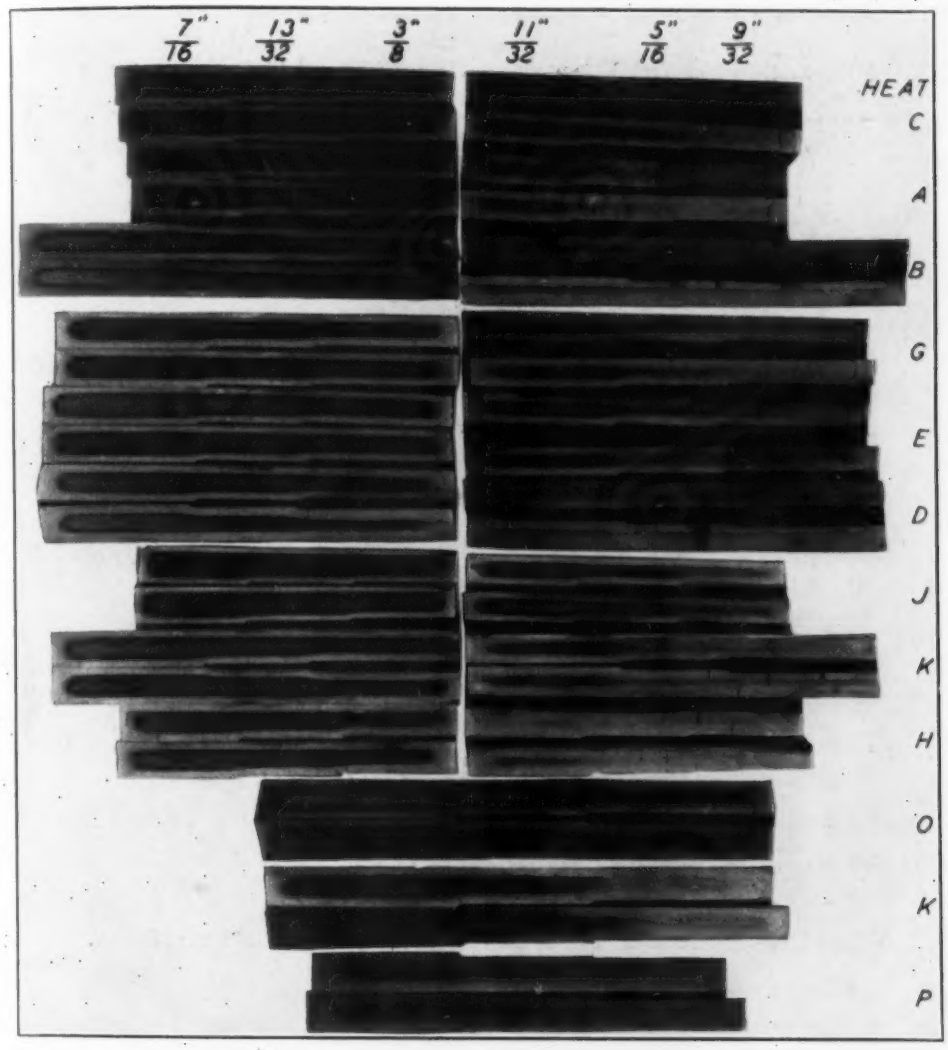


Fig. 7—Effect of Carbon Content on Hardenability. Mfg. Z, Table IV. 0.75, 0.85, 0.95 and 1.05 Per Cent Carbon Steel.

is shown in Table V and the etched tests of the specimens are shown in Fig. 8.

Comparison of Hardening Range of Two Brands of Steel Same Chemical Specification

Production tests made on silicon-chromium tool steels were amplified to include maximum hardening range of this material which ordinarily has a hardenability of not less than No. 14 and not more than No. 16. Results are shown in Table VI and Figs. 9 and 10.

Table IV
MFG Z. Effect of Carbon Content on Hardenability of Plain Carbon Steels of the Following Analysis

Lab. No.	Heat No.	Size	C	Mn	P	S	Si	Cr	Ni	Hardenability
C	X-253	4 " sq.	0.74	0.25	0.007	0.04	0.21	...	...	10
A	H-1377	4 " sq.	0.74	0.24	0.010	0.016	0.24	...	...	11
B	X-2104	5 " sq.	0.75	0.24	0.010	0.013	0.25	...	...	12
G	H-650	5 " sq.	0.85	0.23	0.015	0.021	0.23	...	...	11
E	W-2135	5 " sq.	0.83	0.20	0.015	0.014	0.23	...	...	11
D	W-2254	5 " sq.	0.86	0.24	0.016	0.018	0.18	...	...	12
J	W-2094	3¾" sq.	0.94	0.23	0.015	0.021	0.18	...	...	10
K	X-1317	5 " sq.	0.93	0.25	0.013	0.016	0.18	...	...	11
H	W-1874	4 " sq.	0.93	0.26	0.011	0.010	0.20	...	...	12
O	W-2369	5 " sq.	1.05	0.21	0.016	0.011	0.24	0.04	0.08	10
K	W-2342	4¾" sq.	1.00	0.22	0.018	0.013	0.25	0.05	0.05	11
P	W-2375	4¼" rd.	1.05	0.21	0.012	0.011	0.25	0.03	0.06	12

Production Tests of Hardenability

For production tests of any steel, the slabs are usually held to three thicknesses. The following illustrations are given of material with No. 10, No. 11, and No. 12 hardenability in both small and large sizes, i. e., under and over 3⅜ inches in diameter. See Table VII and Fig. 11.

The chart shown in Fig. 12 was made to determine the relation of analysis to hardenability for 118 heats.

From this chart it can be seen that chemical composition has no relation to the hardenability number.

Effect of High Temperature upon Hardenability Classification

A disk from two heats of 1.00 to 1.10 per cent plain carbon tool steel previously tested for hardenability range and found to be No. 9 (Heat JX4002) and No. 12 (Heat JX4292) were treated as follows, to determine what effect high heating before oil treating and hardening would have upon original classification.

Heated to 2200 degrees Fahr. (Optical pyrometer used to check temperature).

Cooled in air.

Oil-treated from 1600 degrees Fahr.

Hardened from 1440 degrees Fahr.

Heat No.	Size	C	Mn	P	S	Si	Cr	Ni	Hardenability No.
JX-4002	4 " Sq.	1.15	0.25	0.010	0.019	0.16	0.01	0.03	9
JX-4292	4½" Sq.	1.05	0.24	0.016	0.022	0.18	0.05	0.01	12

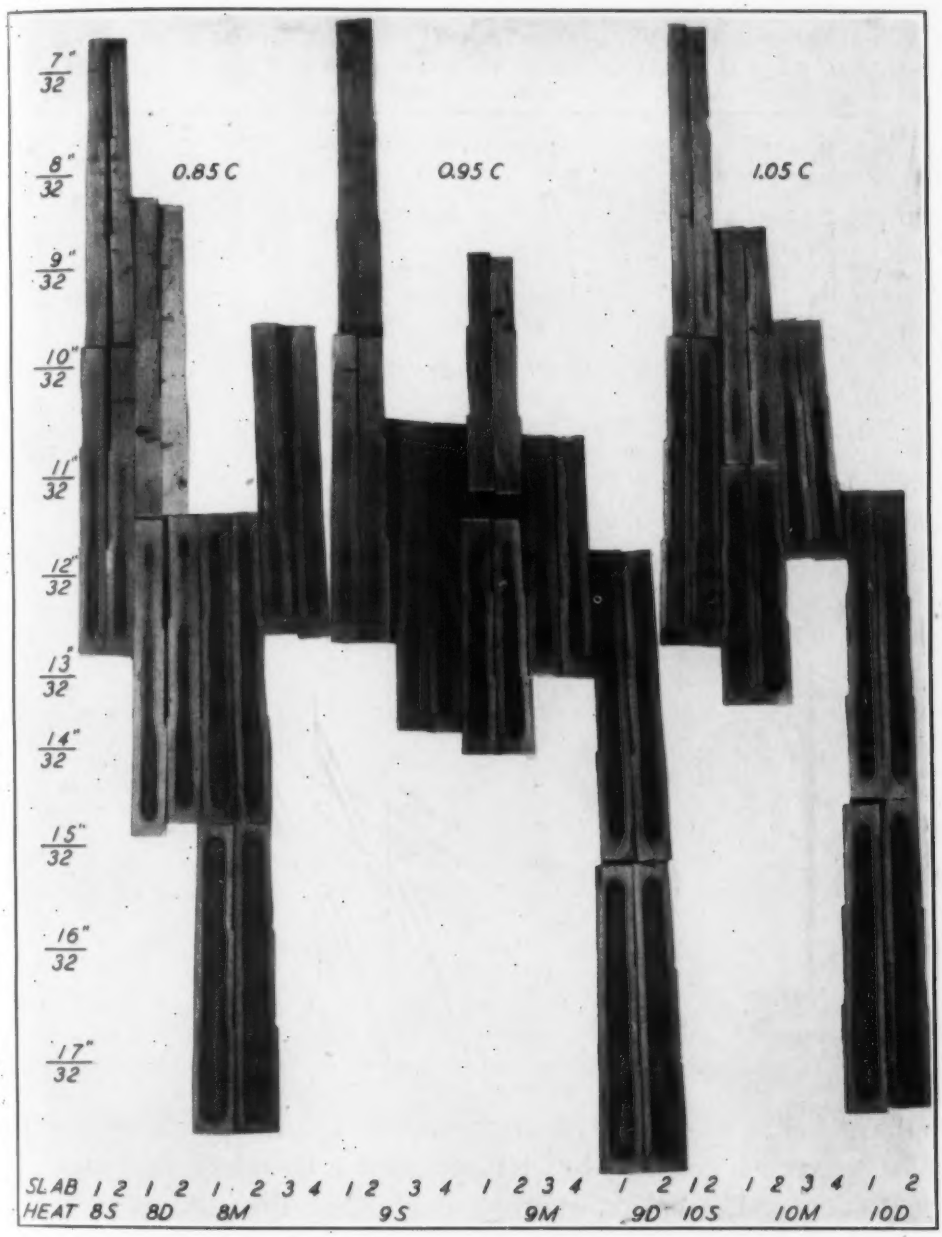


Fig. 8—Effect of Carbon Content on Hardenability. Mfg. V, Table V. 0.85, 0.95 and 1.05 Per Cent Carbon Steel.

Results indicate that the high heating before hardening has no effect upon the hardenability of the material. Fig. 13.

Reproduceability of Results

In order to prove that hardenability results can be reproduced

Table V

MFG V. Effect of Carbon Content on Hardenability of Plain Carbon Steels of the Analysis Below

Lab. No.	Heat No.	Size	C	Mn	P	S	Si	Cr	Ni
8S	HT24751	4 " sq.	0.85	0.27	0.012	0.018	0.15	0.08	0.07
8M	20718	4 " sq.	0.80	0.28	0.015	0.009	0.16	0.07	0.08
8D	HT20381	4 " sq.	0.80	0.30	0.020	0.018	0.17	0.08	0.09
9S	HT25252	4 " sq.	0.91	0.26	0.015	0.019	0.09	0.13	0.11
9M	HT24578	3⅛" rd.	0.94	0.31	0.015	0.020	0.14	0.06	0.11
9D	HT23957	4 " sq.	0.95	0.31	0.020	0.013	0.14	0.09	0.08
10S	HT20975	4 " sq.	1.05	0.22	0.011	0.017	0.08	0.02	0.04
10M	HT24237	3⅛" rd.	1.07	0.31	0.011	0.014	0.21	0.07	0.05
10D	HT24538	4 " sq.	1.01	0.39	0.022	0.012	0.20	0.08	0.11

HARDENABILITY TEST

Thickness of Slabs in 32nds

Lab. No.	Slab No.	7	8	9	10	11	12	13	14	15	16	17	Hardenability No.
8S	1	NC	NC	NC	NC	NC	C						
	2	NC	NC	NC	NC	NC	C						12
8M	1			NC	NC	NC	NC	C	C				
	2			NC	NC	NC	NC	C	C				13
8D	1						C	C	C	C	C	C	
	2						C	C	C	C	C	C	
	3				NC	VSC	C						
	4				NC	VSC	C						12
9S	1	NC	NC	NC	NC	NC	C						
	2	NC	NC	NC	NC	NC	C						12
	3					NC	C	C					
	4					NC	C	C					
9M	1			NC	NC	NC	NC	C	C				
	2			NC	NC	NC	NC	C	C				13
	3					NC	NC	C					
	4					NC	NC	C					
9D	1						NC	C	C	C	C	C	
	2						NC	C	C	C	C	C	13
10S	1	NC	NC	NC	C	C	C						
	2	NC	NC	NC	C	C	C						10
10M	1			NC	NC	SC	C	C	C				
	2			NC	NC	SC	C	C	C				11
	3				NC	C	C						
	4				NC	C	C						
10D	1						NC	C	C	C	C	C	
	2						NC	C	C	C	C	C	13

NC—No Core
VSC—Very Slight Core
C—Core

and checked, disks were taken from several different bars of the same size and heat of 1.00 to 1.10 per cent carbon tool steel used in production and tested on different days. See Fig. 14.

The composition and hardenability results are as follows:

Heat No.	Size	No. Pieces Tested	C	Mn	P	S	Si	Cr	Hardenability No.
W2040	2⅜" rd.	4	1.08	0.23	0.017	0.014	0.25	0.03	11
W1940	3½" rd.	2	1.05	0.21	0.017	0.012	0.20	0.04	10

All four tests on 2⅜-inch round steel gave a hardenability of 11 and both tests on 3½-inch round steel gave a hardenability of 10.

These results supplemented by many others show the repro-

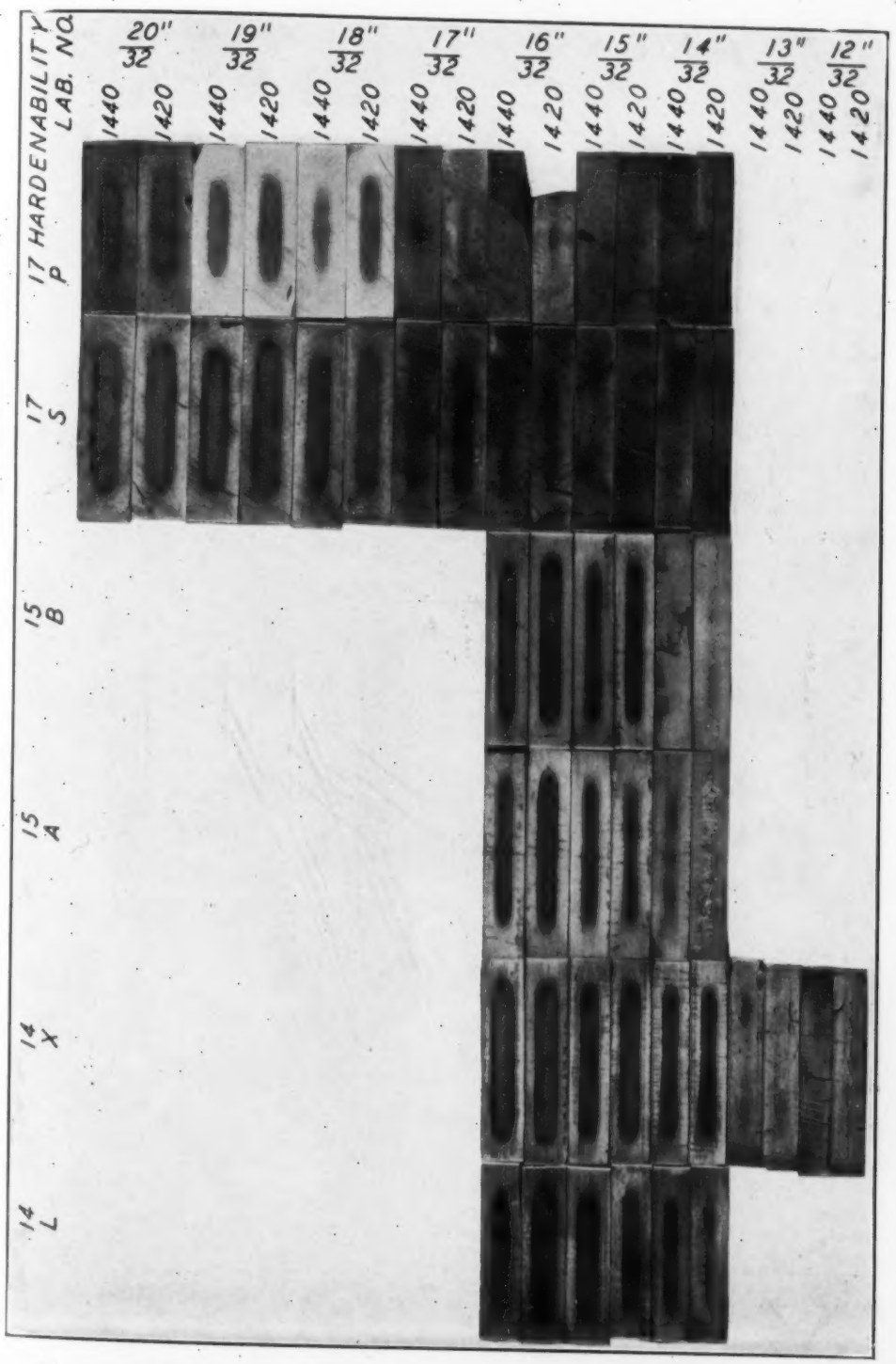


Fig. 9—Showing Variation Found Between Five Heats of Silicon-Chromium Tool Steel. Mfg. Z, Table VI.

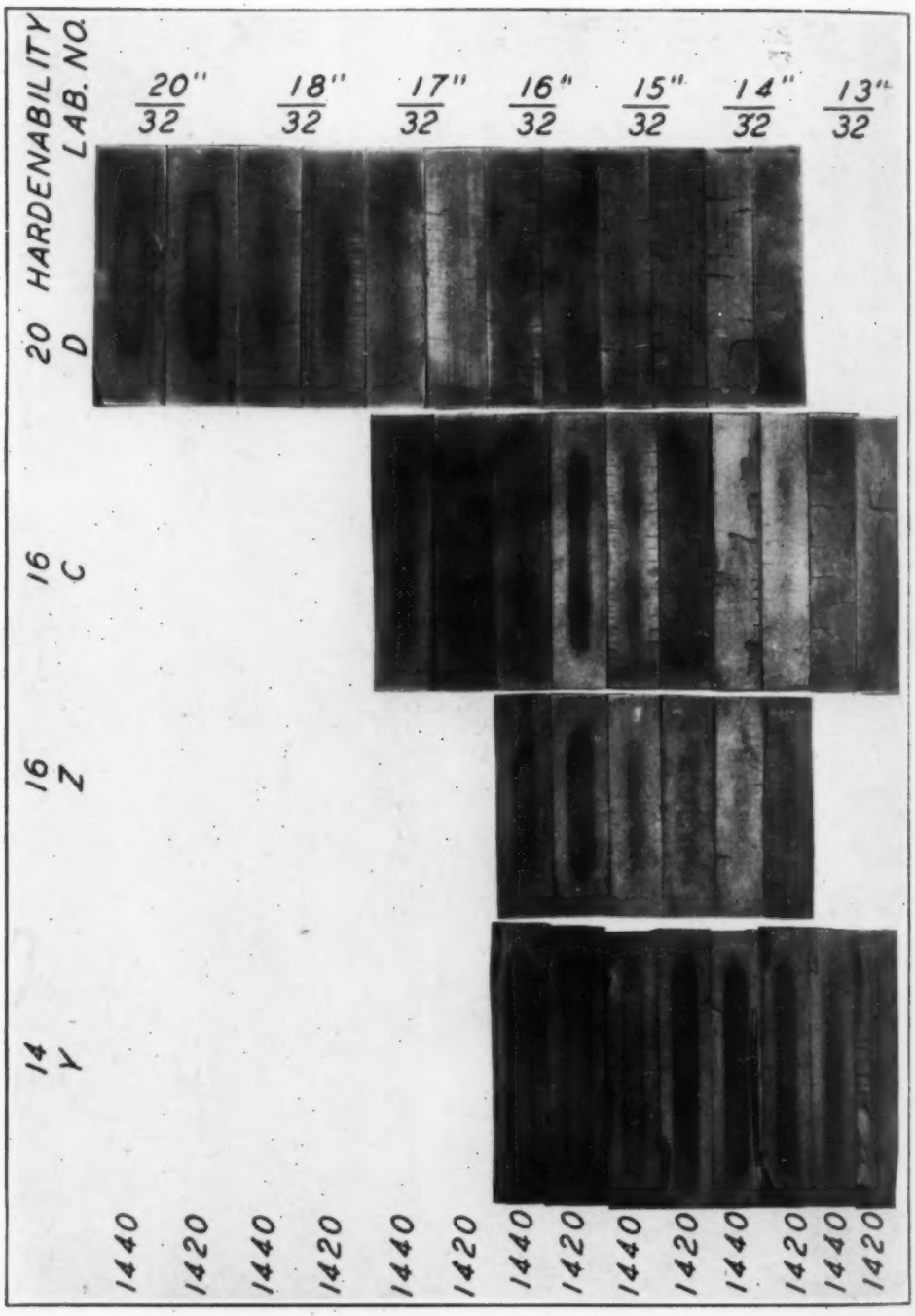


Fig. 10—Showing Variation Found Between Four Heats of Silicon-Chromium Tool Steel. Mfg. V, Table VI.

duceability of the hardenability tests and also show that the hardenability number for any one heat is constant.

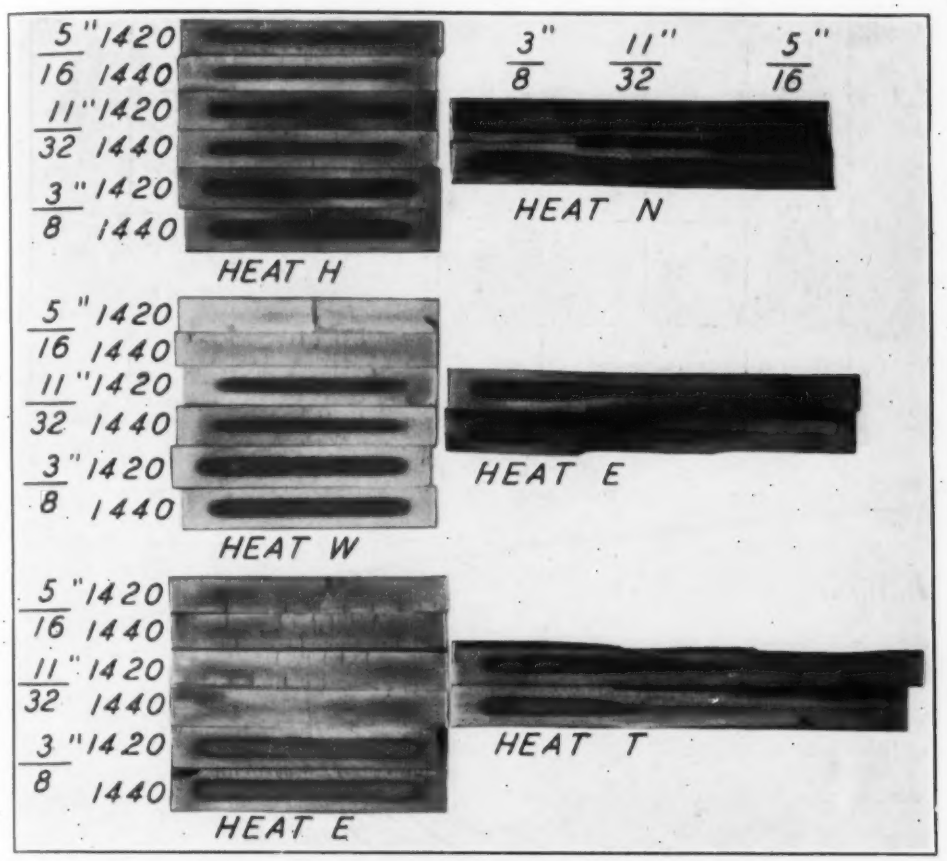


Fig. 11—Showing Three Classes of Hardenability Found in Production Tests of a 1.00 to 1.10 Per Cent Carbon Tool Steel in Each of the Two Types of Test Used, Table VII.

Table VI

Comparison of Hardening Range of Two Brands of Silicon-Chromium Tool Steel

Lab. No.	Heat No.	Size	C	Mn	P	S	Si	Cr	Ni	Hardenability No.
			MANUFACTURER Z							
L	W-1396	2 " rd.	0.99	0.21	0.014	0.015	0.45	0.22	...	14
X	H-1756	2⅜" rd.	0.98	0.22	0.012	0.018	0.44	0.17	...	14
A	W-1013	2⅜" rd.	0.93	0.24	0.013	0.020	0.48	0.20	...	15
B	H-1569	2½" rd.	0.96	0.25	0.011	0.015	0.44	0.18	...	15
S	W-1877*	2⅜" rd.	0.93	0.26	0.011	0.009	0.43	0.25	Trace	17
P	W-1877*	2 " rd.	0.93	0.26	0.011	0.009	0.43	0.25	Trace	17
			MANUFACTURER V							
Y	23992	2½" rd.	0.96	0.27	0.014	0.012	0.40	0.12	0.15	14
Z	X24160	2 " rd.	0.92	0.30	0.011	0.017	0.45	0.17	...	16
C	X23455	2½" rd.	0.91	0.20	0.012	0.016	0.54	0.19	...	16
D	X24149	2⅜" rd.	0.92	0.30	0.014	0.016	0.48	0.23	0.15	20

*Note same classification of two different sizes from the same heat.

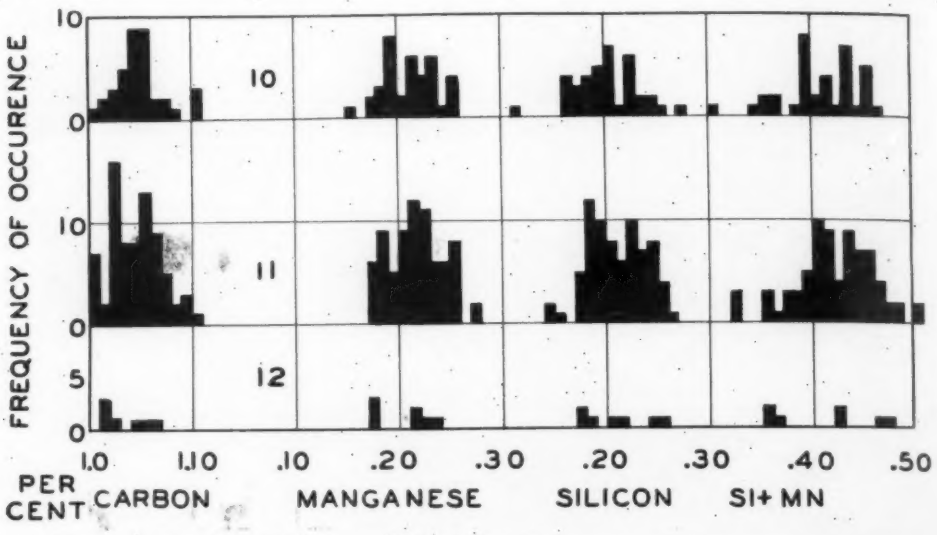


Fig. 12—Showing 118 Heats Plotted for Frequency of Occurrence of Carbon, Manganese, Silicon, Manganese plus Silicon in Each of Three Hardenability Classes, 10, 11 and 12 Found in This Steel.

Modified Hardenability Test

Trouble was experienced in the heat treating department with certain parts, some of which hardened too deeply when subjected to

Table VII
Production Tests of Hardenability

Lab. No.	Heat No.	Size	C	Mn	P	S	Si	Cr	Ni	Hardenability No.
H	W-1833	2⅜" rd.	1.05	0.21	0.011	0.008	0.22	0.03	...	10
W	W-1916	2½" rd.	1.06	0.25	0.015	0.011	0.25	0.03	...	11
E	C-308	2½" rd.	1.01	0.22	0.012	0.006	0.20	0.03	...	12
N	W-2151	3½" rd.	1.04	0.23	0.014	0.013	0.20	0.05	0.06	10
E	W-2278	3¾" rd.	1.05	0.24	0.013	0.009	0.18	0.04	...	11
T	W-2385	4¼" rd.	1.02	0.23	0.014	0.011	0.24	0.03	...	12

The following percentage of each class was found

Total heats examined to July 1, 1929	135	
Total heats 10 hardenability	42	31.1 per cent
Total heats 11 hardenability	84	62.2 per cent
Total heats 12 hardenability	9	6.6 per cent

the same treatment as others on the same job, from the same steel which hardened to a normal depth. A piece of the former was marked No. 2 and a piece of the latter No. 1, and a modified test was made as shown in Fig. 15.

Disks were fitted into drilled and reamed holes in stainless iron slabs which were of the usual three thicknesses, conforming to the standard test for this material, that is, $\frac{5}{16}$ inch, $\frac{11}{32}$ inch, and

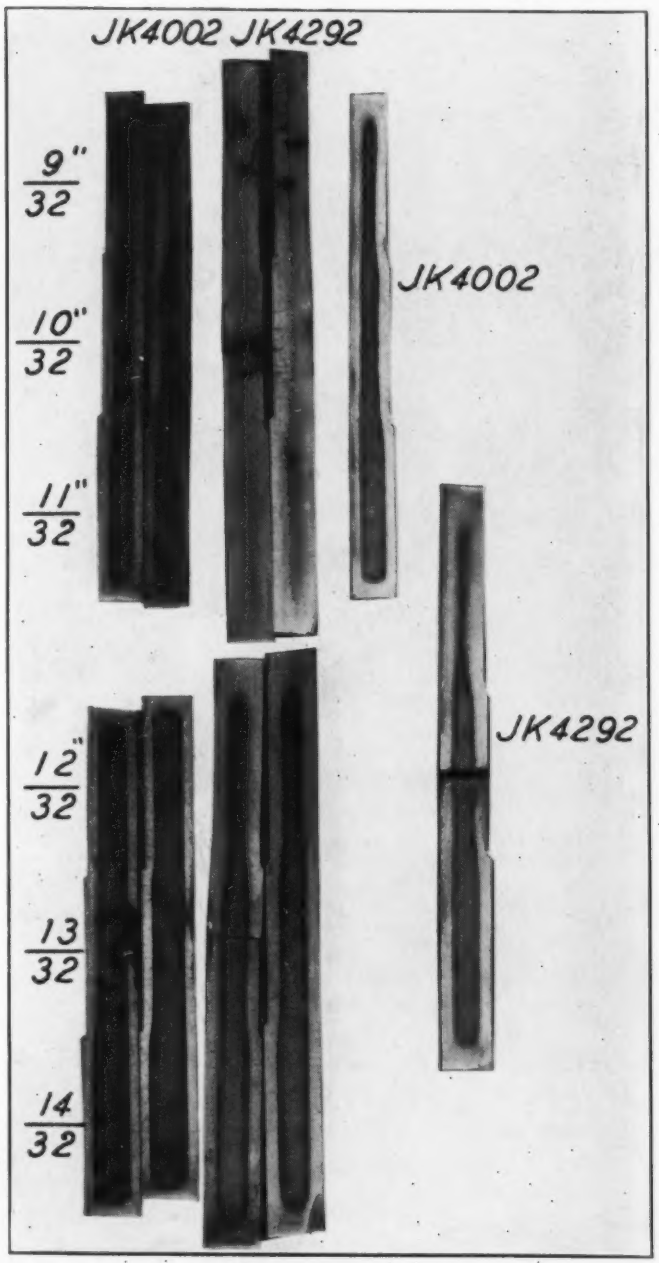


Fig. 13—Showing Original Tests in Duplicate (on left) of Heats JK4002, Hardenability No. 9, and Heat JK4292, Hardenability No. 12, Compared with Single Slabs (on right) Retested After Heating to 2200 Degrees Fahr.

3/8 inch. An extra series of disks was placed in the 5/16 inch slab. These slabs were then oil-treated from 1520 degrees Fahr., and hardened from 1440 degrees Fahr., the disks removed and etched. The

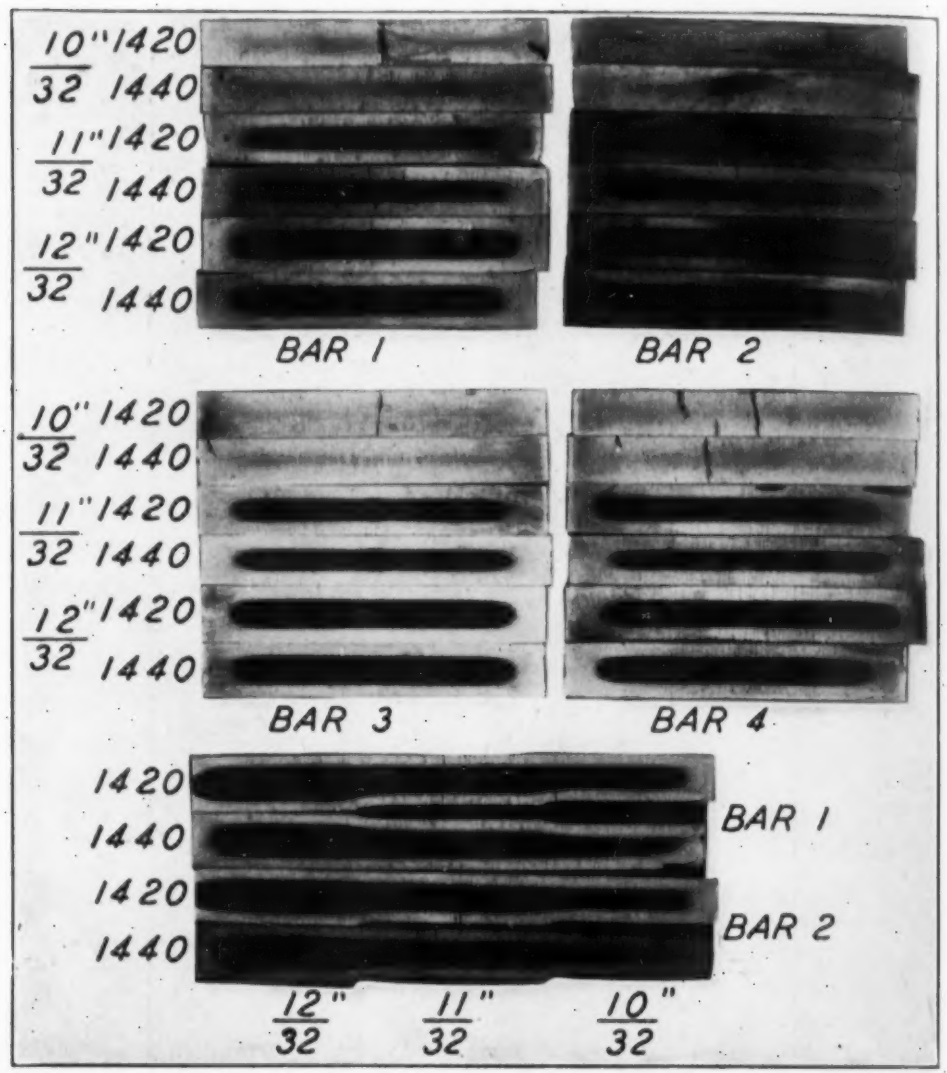


Fig. 14—Showing Four Bars from Same Heat and Two Bars from Another Heat Hardened in Duplicate on Different Days to Show Reproduceability of Hardenability Test.

photograph clearly shows the difference in hardenability of the steel.

The part marked No. 1, which was satisfactory in a production way, has a hardenability number of 11. The hardenability of the other material was above 12, the test not being extensive enough to determine the true hardenability number. It will also be noted that one of the small disks, marked No. 2, is cracked. This feature is characteristic of the thin sections of steel having high hardenability numbers. Our tests seem to indicate that there is a critical

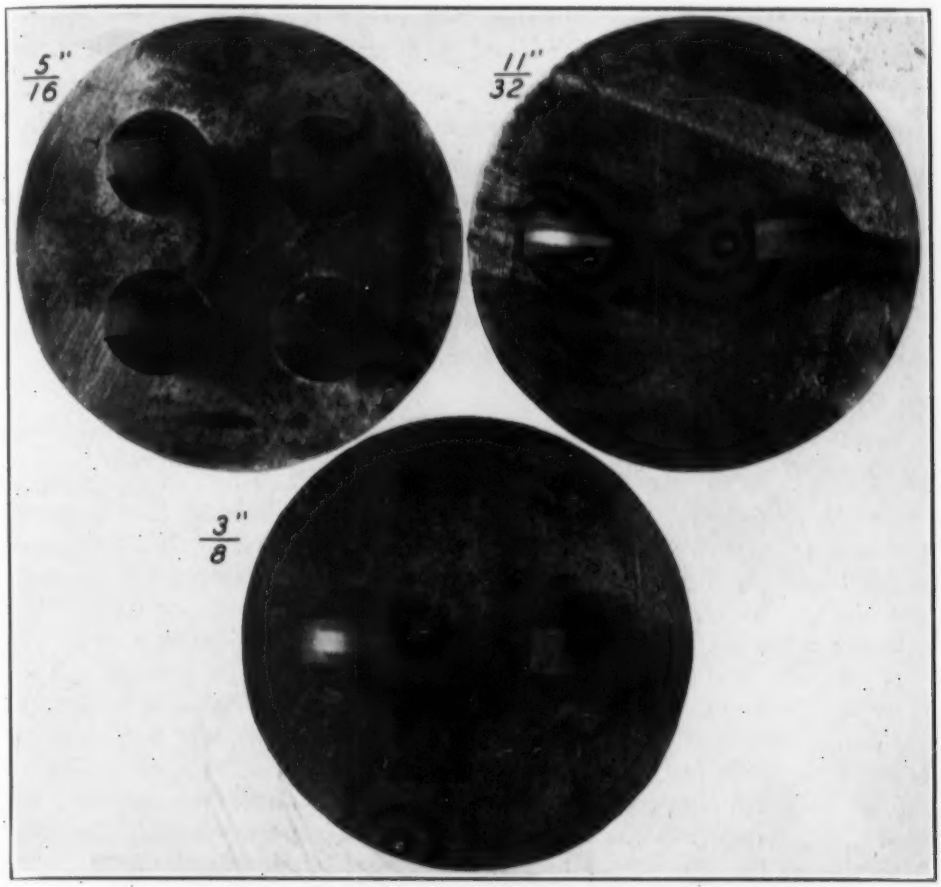


Fig. 15—Showing Variation* in Hardening Test, Using Disks of Material in Stainless Iron Slabs, Comparing Deep ? and Shallow ? Hardening Material.

thickness of section for each hardenability below which sections which harden through will almost invariably crack badly. The number of sections (in steps of $\frac{1}{32}$ inch) between the critical section and the first section to have a core is very much less in the same type steel of high hardenability than in that of low.

Conclusion

The above tests show that there is a variability in the manner in which steel of approximately the same chemical analysis responds to a standardized hardening operation. This offers an explanation for the variations which are often encountered in hardened parts which are unexplainable on the basis of chemical analysis. A real-

*Acknowledgment is made to Dr. H. Styri for suggesting this variation in method.

ization of this difference in materials has led to very great improvement in uniformity of hardened product in the plant with which the writer is associated. A more general realization of the necessity for such control will have to be made in any shop where specialized hardening is required to produce parts of superior quality.

Acknowledgment is made to the metallurgical staff of Ingersoll-Rand Co. for their assistance in the work connected with the production of this paper, and also to F. P. Martin, past master in the art of hardening, and superintendent of the heat treating and forge departments of Ingersoll-Rand Co., who has been an inspiration in all of this work.

DISCUSSION

G. V. LUERSSEN:[1] There are two points in connection with Mr. Shepherd's test which I believe should be stressed further. The first of these is that the test is extremely simple and extremely accurate. It is accurate for the reason that the $\frac{1}{32}$-inch step between gages represents only $\frac{1}{64}$-inch, or 0.015-inch in actual penetration. The usual methods of measuring penetration involve quenching a uniform section of a size which will not harden through, e. g., 1 inch diameter. It is apparent that slight differences in penetration on such a test are rather difficult to measure, but are readily measured by Mr. Shepherd's test on account of the fact that these slight differences are greatly magnified. In this connection it is interesting that in making comparisons between Mr. Shepherd's test, and penetration tests on 1-inch round sections, similarly quenched, it was found that the former test showed a penetration approximately $\frac{1}{64}$-inch deeper than the latter, based on the thickness of the step which just hardened through.

The second point to be stressed is the fact that on account of the delicacy of the test as pointed out above, it is necessary to grind the surfaces to a very accurate thickness. An error of as much as 0.002-inch in thickness will often affect the results. This, however, does not detract in the least from the value of the method, and Mr. Shepherd is to be congratulated upon having devised this very ingenious test.

[1]Member A. S. S. T. Metallurgical department, Carpenter Steel Co., Reading, Pa.

Educational Section

These Articles Have Been Selected Primarily For Their Educational And Informational Character As Distinguished From Reports Of Investigations And Research

THE CONSTITUTION OF STEEL AND CAST IRON
SECTION II—PART XIV

By F. T. Sisco

Abstract

This installment, the fourteenth and last of the series, discusses briefly the effect of the various alloying metals on the structure of the iron-carbon alloys. The general effect of the alloying elements is first described, particularly as regards the lowering of the transformation point in cooling. Following this and in order, the common alloying elements are taken up. These include nickel, manganese, chromium, vanadium, tungsten, molybdenum, silicon and cobalt. A brief conclusion ends the chapter.

IN our discussion of the constitution of steel and cast iron we have, up to this point, confined ourselves to the plain carbon steels, the iron-carbon alloys containing from a trace to 1.70 per cent carbon; and to the cast irons, the iron-carbon alloys containing between 1.70 and 6.67 per cent carbon. By far the greatest percentage of commercial steels are of the so-called plain carbon class, that is, their characteristic properties and structures are due almost wholly to the amount and condition of the carbon they contain. But our discussion would not be complete if we omitted a brief consideration of that large class of ferrous materials known as alloy steels, which owe their distinctive properties and structure to the presence of one or more alloying elements in addition to the carbon normally present.

It will be impossible for us to describe each well known alloy

This is the twenty-fourth and last installment of this series of articles by F. T. Sisco. The several installments which have already appeared in TRANSACTIONS are as follows: June, July, August, September, November, 1926; January, February, April, June, August, October, 1927; February, April, June, November, 1928; January, March, May, June, July, September, October, December, 1929.

The author, F. T. Sisco, a director of the society, is chief of the metallurgical laboratory, Air Corps, War Department, Wright Field, Dayton, Ohio.

steel; a book, yes a whole library, would be necessary to do justice to this vast and complex field. The most that we can hope to accomplish in a single chapter is to summarize very sketchily the effect of each of the common alloying metals on the properties, and especially upon the structure. In other words we will not be concerned with alloy steels as commercial products, but rather, we will be most interested in the alloying element for its effect upon the equilibrium diagram and hence upon the structural changes taking place in the iron-carbon alloys when they are heated and cooled through the transformation points.

The common alloying elements which we will consider in our discussion include manganese in amounts between 1.00 and 15.00 per cent, nickel, chromium, vanadium, tungsten and molybdenum. The great bulk of our commercial alloy steels contain one or more of these elements. Alloy steels are classed as ternary when they contain iron, carbon, and one of the alloying elements; or quaternary when they contain two alloys in addition to iron and carbon.

The alloying elements may be divided into two species: those which do not react with carbon to form a carbide, and those which do. In the first class we have nickel which is soluble in both gamma and alpha iron, and possibly vanadium and molybdenum. In the second class chromium and tungsten form carbides, and in certain amounts it is thought that vanadium and molybdenum do likewise. Manganese, as it well known, forms the carbide Mn_3C which, in steel, acts very much the same as iron carbide, Fe_3C.

General Effect of the Alloying Elements

The first and most important effect of the addition of an alloying element is that it lowers the critical point, Ar_1. This is shown graphically in Fig. 95 taken from Sauveur.[80] With the carbon constant at 1.00 per cent the critical point is lowered progressively as the percentage of the special element increases. Suppose, for example, we have a steel containing 1.00 per cent carbon and 1.00 per cent of the special element. The normal transformation of 1.00 per cent plain carbon steel in cooling occurs at 1290 degrees Fahr. (700 degrees Cent.) at which point the austenite undergoes transformation into pearlite. But if 1.00 per cent of an alloying element is added to this high carbon steel, upon slow cooling this transformation occurs

[80]Albert Sauveur, "Metallography and Heat Treatment of Iron and Steel," Cambridge Press, 1926, page 311.

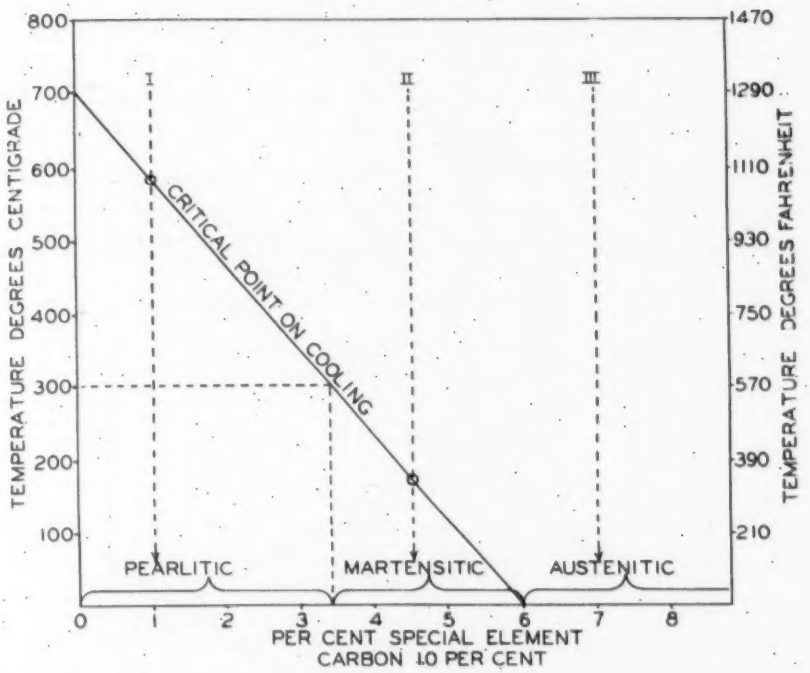


Fig. 95—The Influence of Special Element on the Position of the Critical Point.

at 1100 degrees Fahr. (590 degrees Cent.). The addition of 1.00 per cent of this alloy has reduced the lower transformation point nearly 200 degrees.

Now suppose that we add 4.5 per cent of the alloying element to our 1.00 per cent carbon steel. When this steel is cooled slowly the transformation of the austenite does not take place until a temperature of 325 degrees Fahr. (160 degrees Cent.) is reached. We have already learned that when a high carbon steel is cooled rapidly from a high temperature the position of the Ar_1 point is lowered progressively as the speed of cooling is increased until when Ar_1 occurs at about 575 degrees Fahr. or below the austenite transforms into martensite instead of the more stable pearlite. Adding 3.50 to 6.00 per cent of an alloying element to a 1.00 per cent carbon steel has the same effect as an accelerated cooling; it lowers the position of the Ar_1 point from its normal temperature of 1290 degrees Fahr. to 575 degrees Fahr. or below. Hence if we cool a 1.00-per cent carbon steel containing 4.50 per cent of the alloying element slowly from a high temperature the transformation of the austenite does not take place until 325 degrees Fahr. is reached (II, Fig. 95) and the structure changes from austenite to martensite which is then stable at atmospheric temperature.

The combined effect of carbon and an alloying element is shown in Fig. 96 also from Sauveur.[81] This diagram pictures graphically the constitution of ternary alloy steels as first conceived by Guillet. In general the facts brought out by this diagram are self-evident. In the first place, if we maintain the amount of carbon constant, for example 1.00 per cent, the normal structure of the steel will be pearlitic if the amount of the alloying element is below 2.50 to 3.50 per

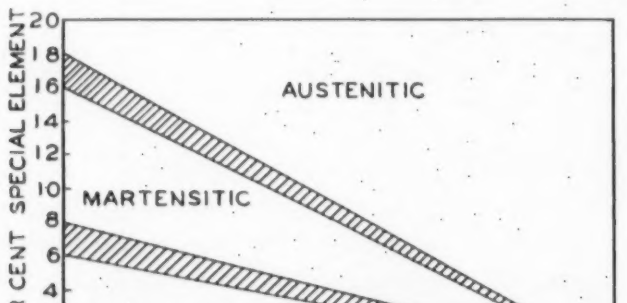


Fig. 96—Constitutional Diagram of Alloy Steels.

cent. The structure changes from pearlitic to martensitic when 3.50 to 6.00 per cent of the alloying element is present and to austenitic when more than 6.00 per cent is present. In the second place it is evident from Fig. 96 that if we maintain the amount of alloying element constant at 4.00 per cent the structure will be pearlitic when the carbon content is between 0.01 and 0.80 per cent, martensitic when the carbon is between 0.80 and 1.30 per cent and austenitic if the carbon is above 1.30 per cent.

The diagram shown in Fig. 96 has been of great value in prophesying the structure and properties of steels containing one alloying element. As it represents a generalization, Fig. 96 should not be interpreted too rigidly. Fig. 95 showing the effect of the alloying element, and Fig. 96 of both alloying element and carbon do prove, however, that the Ar_1 point is depressed by the addition of an alloying metal and that by the proper combination of the alloying element and the carbon we can secure the same structure and properties by relatively slow cooling that results from the very rapid cooling of a plain carbon steel.

[81]Loc. cit. page 308.

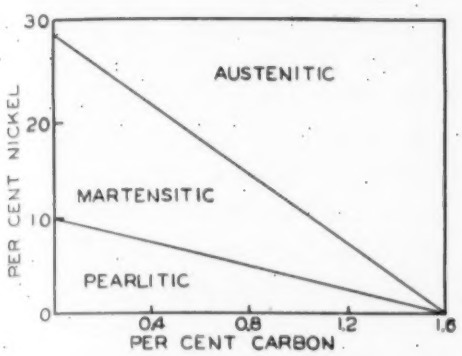


Fig. 97—Constitutional Diagram of Nickel Steel. (Guillet)

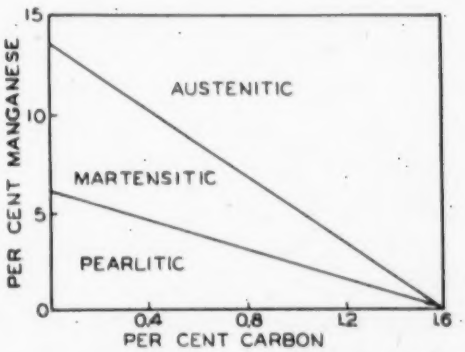


Fig. 98—Constitutional Diagram of Manganese Steel. (Guillet)

Effect of Nickel on the Structure of Steel

Nickel as an alloying element in steel is unique in that it is the only common metal that is soluble in iron and steel in all proportions. So far as is known, when nickel is added to molten iron or steel it does not form a carbide or react chemically in any way with any element in the steel but goes into solution in the molten metal. When the steel solidifies the nickel is in solution in the gamma iron and remains in solution in the alpha iron when the allotropic change is complete. It is of great importance to us that nickel is soluble in iron. In the first place this characteristic is responsible for a series of steels having very valuable properties. But it also has some disadvantages. When nickel is once dissolved in iron we cannot get it out again. There is no known method for removing nickel from steel, consequently, since a large amount of nickel steel scrap is remelted, we must watch very carefully to prevent it from contaminating material in which it is not desired.[82]

Nickel lowers the transformation temperature in cooling to a marked degree. It is evident from Fig. 97 that a steel containing between 12 and 27 per cent nickel is martensitic after slow cooling even though no carbon is present. With more than 26 per cent nickel the Ar_1 point is lowered to atmospheric temperature or below so that the structure is austenitic even after slow cooling. With 1.00 per cent carbon and 5.00 per cent nickel, the steel is martensitic and with the same amount of carbon and about 9.00 per cent nickel it is austenitic at room temperature.

A characteristic effect of nickel is that it increases the hysteresis gap between the critical point on heating, Ac, and the critical point

[82]Nickel is usually considered to be harmful in steels used for tools.

in cooling, Ar. Nickel lowers both the Ar_1 point and the Ac_1 point but its effect upon the Ac_1 point is only half as great as upon the Ar_1. For every two degrees that the Ar_1 point is lowered the Ac_1 point is lowered about one degree. In high nickel steels the gap between Ac_1 and Ar_1 may be several hundred degrees. Another characteristic of nickel when alloyed with steel is that it reduces the eutectoid ratio; a steel containing 3.00 per cent nickel and 0.70 to 0.75 per cent carbon, is composed wholly of pearlite. The nickel structural steels containing 3.00 to 3.50 per cent nickel contain much more pearlite for a given carbon percentage than the plain carbon steels. In addition to these effects upon the structure of steel, nickel intensifies the hardening power. By this we mean that low nickel steels containing less than 5.00 per cent nickel harden more intensely than the corresponding carbon steels. In other words the same or greater hardness will result from quenching a 3.50 per cent nickel steel in oil than would result from quenching a plain steel of corresponding carbon content in water. This has the advantage that distortion and warping are minimized.

From the diagram shown in Fig. 97 we can conveniently divide the nickel steels into three classes; pearlitic, martensitic and austenitic. The pearlitic steels containing between 1.00 and 5.00 per cent carbon are the most common. When used without chromium or some other alloying element it is of little advantage to add less than about 3.00 per cent nickel to steel. In these small amounts (3.00 to 5.00 per cent) nickel increases the hardness, strength, elastic limit and resistance to shock and at the same time improves the ductility somewhat. The most common nickel steel, S.A.E. 2330, contains 0.30 per cent carbon and 3.50 per cent nickel. When quenched in oil and tempered between 800 and 1100 degrees Fahr. it will have an ultimate strength of 125,000 to 150,000 pounds per square inch and an elongation of 15 to 25 per cent in two inches.[83]

There are two austenitic nickel steels used commercially; "Permalloy," containing 78.5 per cent nickel and 21.5 per cent iron, which has a high magnetic susceptibility; and "Invar" containing about 36 per cent nickel, which has a low coefficient of expansion and so is valuable for measuring apparatus, clocks, and other precision instruments. Invar is used extensively in the form of struts in aluminum alloy pistons for automotive and aircraft engines.

---

[83]Complete heat treatments and physical properties of nickel steels are given in the A.S.S.T. and S.A.E. handbooks.

Effect of Manganese on the Structure of Steel

When added to pure molten iron manganese dissolves in all proportions and remains in solution when the metal is solid. But when carbon is present the manganese reacts with this element to form manganese carbide, Mn_3C, a chemical compound similar in behavior to iron carbide, Fe_3C. The effect of manganese on the structure of steel is shown in Fig. 98. It will be noted that this element acts in very much the same way as nickel but is about twice as potent in its effect on the lower critical point. In carbonless iron it is necessary to add 27 per cent nickel to produce an austenitic structure after slow cooling; 14 per cent manganese results in the same structure. Like nickel, manganese increases the gap between the Ac and Ar critical points. It also reduces the amount of carbon necessary to produce a structure consisting wholly of pearlite; with 1.00 per cent manganese the eutectoid occurs at about 0.75 per cent carbon.

On account of its value as a deoxidizer and general scavenger manganese is found in practically all steels but the amount is usually less than 1.00 per cent. It has long been thought that when more than 1.00 per cent manganese (and less than 11.00 per cent) was present, this element would produce brittleness. This is now known to be incorrect; it is only when the percentages of manganese and carbon are high enough to produce a martensitic structure upon slow cooling, that brittleness is characteristic of the steel. Consequently, some of the pearlitic manganese steels have come into extensive use. Among these are the well known oil-hardening die steels containing about 0.90 per cent carbon and 1.50 per cent manganese. For structural purposes steel containing 0.35 to 0.50 per cent carbon and 1.00 to 2.00 per cent manganese have been used successfully. When properly treated these steels show as good properties as the 3.50 per cent nickel steels. There is little doubt but that the pearlitic manganese steels will be widely used in the future.

The martensitic manganese steels like the martensitic nickel steels are of no industrial importance. They are hard and brittle and cannot, of course, be annealed. The austenitic manganese steels are of great value and are so widely used that they are familiar to everyone. They ordinarily contain 1.00 to 1.25 per cent carbon and 11.00 to 14.00 per cent manganese. When cooled slowly from a high temperature the structure of this material is austenitic containing

some martensite and numerous particles of hard brittle carbide. In this condition the steel is worthless but if it is heated to above the Ac_{cm} point (about 1950 degrees Fahr.) the carbides go into solution and are retained in solution when the steel is quenched in water.

After heat treatment, high manganese steel is typically austenitic.[84] It has an ultimate strength of about 100,000 pounds per square inch, an elastic limit of approximately 40,000 pounds per square inch and an elongation of 30 to 60 per cent in two inches. The most valuable property of austenitic manganese steel is its high resistance to wear and abrasion. This characteristic is well known and has received so much attention that it can be dismissed with a few words.[85] As heat treated this austenitic structure is relatively soft (less than 250 Brinell) but under severe cold work this soft austenite becomes very hard, so hard that it cannot be machined even with the best tools. Unless the wear is severe, austenitic manganese steel will not harden appreciably. This is evidenced by the fact that buckets for steam shovels and dredges wear out rapidly when working in sand or other soft earths but last long when digging stone and hard materials. Although the strength properties of austenitic manganese steel are very much the same as other alloy steels of like structure it is much superior in its ability to resist wear and abrasion. Austenitic manganese steels are not resistant to corrosion.

Effect of Chromium on the Structure of Steel

Chromium when added to molten carbonless iron dissolves and remains in solution when the material solidifies. When carbon is present the chromium reacts with this element to form complex carbides of unknown or uncertain composition. These carbides are usually assigned the indefinite chemical formula, m Cr_xC_y, n Fe_3C; where m, n, x, and y are unknown quantities. The structural diagram after Guillet is reproduced in Fig. 99. As shown by this diagram increasing the amount of chromium and carbon produces a martensitic structure upon slow cooling, but, unlike nickel and manganese, a further increase in these two elements does not result in the steel becoming austenitic; carbides are formed instead. These carbides are harder than ordinary cementite and when heated above

[84]The structure was illustrated in a former installment. Transactions, August 1926, page 282. See also the reference given in footnote 85.

[85]For a comprehensive discussion of the constitution of high manganese steels see V. N. Krivobok, Transactions, American Society for Steel Treating, June, 1929, Vol. 15, page 893.

Ac_{em} go into solution in gamma iron much slower than does the carbide of iron.

Chromium increases the strength, elastic limit and hardness of steel but reduces the ductility to a marked degree. It increases the hardening power and makes the resulting martensite more stable. For this reason it is valuable in steels to be used for tools. The pearlitic chromium steels containing about 1.00 per cent carbon and

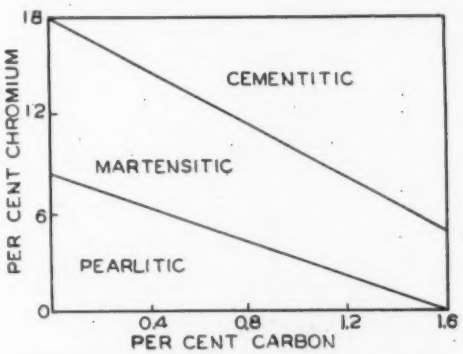


Fig. 99—Constitutional Diagram of Chromium Steel. (Guillet)

0.50 to 1.50 per cent chromium are very hard after heat treatment and so are extensively used for tools and for ball and roller bearings and ball races.

The addition of 0.50 to 1.50 per cent chromium to nickel steels containing 0.30 to 0.50 per cent carbon and 2.00 to 3.00 per cent nickel change these from pearlitic to a structural condition in which they are martensitic after relatively slow cooling. There is a large variety of these nickel-chromium steels in use in the automotive and aircraft industry where they find wide application for gears, crankshafts, connecting rods and other highly stressed parts. The proportion of carbon, nickel and chromium is so balanced in many of them that very slow cooling, as in the furnace, results in a pearlitic structure accompanied by easy machinability; but at the same time the steel can be made very hard by quenching in oil or even by cooling in air from about 1450 degrees Fahr. The oil-hardening and air-hardening nickel-chromium steels (S.A.E. series 3100, 3200, 3300, and 3400) are among the most valuable known to industry for structural use where great strength, toughness and ductility are required.

Chromium is unique among the alloying metals in that it greatly increases the resistance of iron to corrosion. As a result of this characteristic we have the well known stainless steels which contain

between 0.30 and 0.50 per cent carbon and about 12.00 per cent chromium. In general, the lower the carbon the higher the resistance to corrosion. In order to attain the best stainless properties the steel must be heated to 1650 to 1950 degrees Fahr., at which temperature the carbides go into solution. The material is then quenched in oil. These quenched steels are used for cutlery on account of their hardness and great resistance to the action of the organic acids present in foods. A modification of these rust-resisting steels is stainless iron containing, usually, less than 0.15 per cent carbon. Since this material will contain little or no excess of carbides it does not need to be heat treated in order to develop its stainless properties. Stainless iron cannot be used for cutlery as it will not harden greatly in heat treatment.

Based upon the results obtained by adding 12.00 per cent chromium to steel, many other alloy steels containing large amounts of chromium, or nickel and chromium, have been developed. Chief among these are the high nickel, high chromium, low carbon, heat-resisting steels and the high chromium, high carbon, die and tool steels. In the first class are included all of the newly developed heat and corrosion resistant steels containing less than 0.15 per cent carbon, 18.00 per cent chromium, and 8.00 per cent nickel. Due to the high percentage of chromium and nickel and the low carbon content these steels are austenitic after slow cooling and are comparatively free from brittle carbides. These heat resisting materials have physical properties characteristic of austenitic steels, an ultimate strength of 100,000 pounds per square inch, an elastic limit of about 40,000 pounds per square inch and an elongation of 50 to 70 per cent in two inches. In contrast to the austenitic manganese steels, these heat resisting steels can be cold-rolled, drawn or formed and can be machined with comparative ease. Although these steels are less than five years old they are already used widely for parts that must withstand corrosion and which must have a fair strength at high temperatures. From them are made numerous household utensils, bank vaults, instruments, wire, ornamental work on buildings, acid and heat resisting pipe, sheet and containers of various sorts and tubing of many shapes and sizes.

Since the transformation range of these austenitic nickel-chromium steels is below atmospheric temperature they cannot be heat treated. The only hardening possible is by cold work. Fig. 100

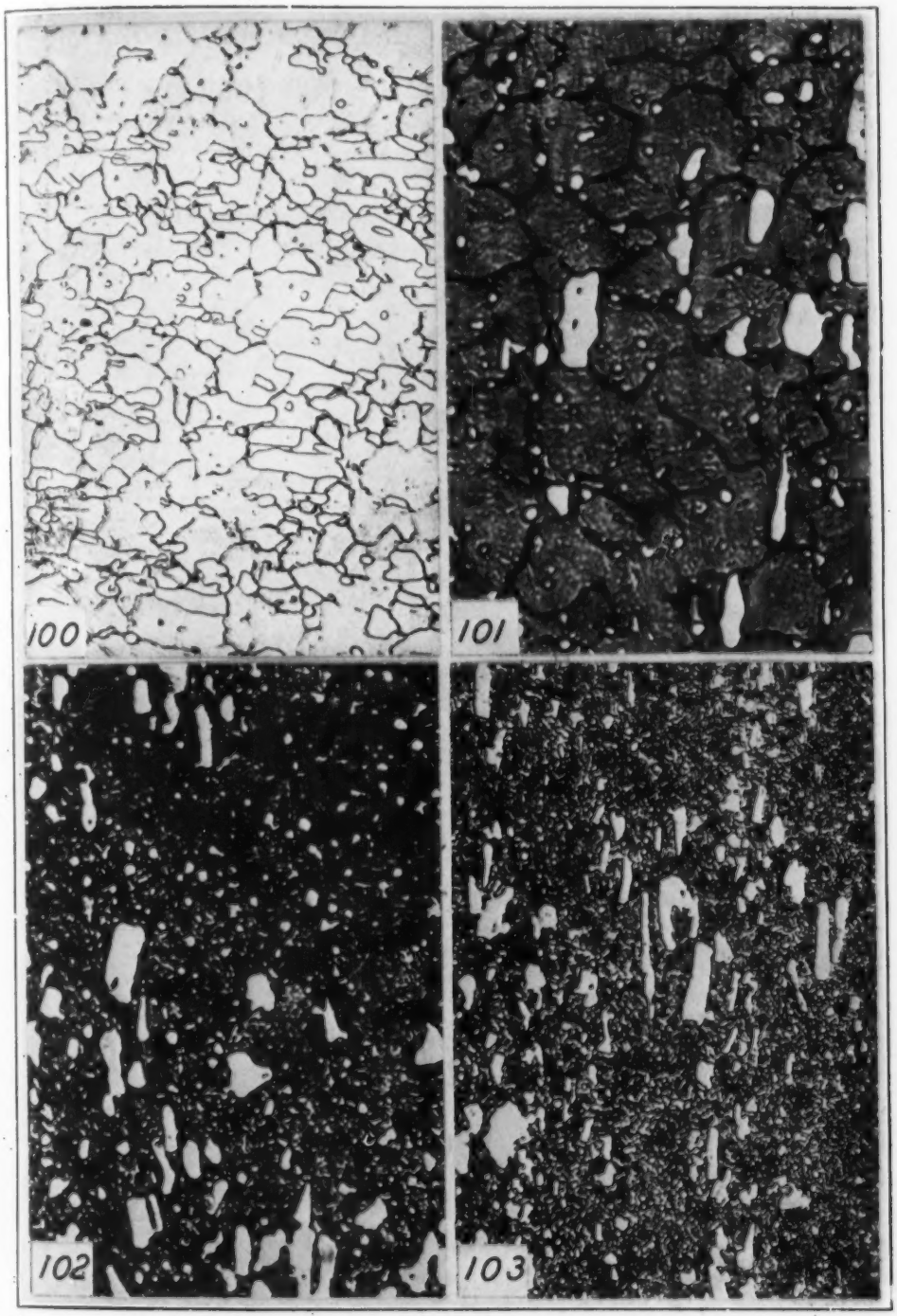


Fig. 100—Structure of Austenitic Nickel-Chromium Steel. Etched in Bromine and Sulphuric Acid. Magnification × 500.
Fig. 101—Austenite and Carbides. Magnification × 750.
Fig. 102—Martensite and Carbides. Magnification × 750.
Fig. 103—Martensite and Carbides. Magnification × 750.
Figs. 101, 102, 103 from Steel Containing 2.00 Per Cent Carbon, 13.00 Per Cent Chromium. All Etched in Ferric Chloride Plus Nitric Acid.

shows the average structure of an austenitic steel containing 0.10 per cent carbon, 18.00 per cent chromium and 8.00 per cent nickel. As these steels are exceedingly resistant to acid attack they are etched with difficulty. In Fig. 100 the etchant used has corroded the boundaries of the austenite grains bringing them into clear view. Unless

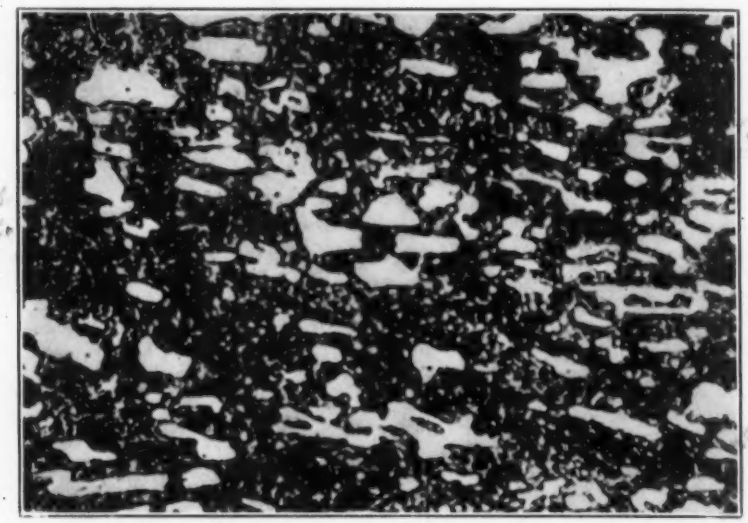


Fig. 104—Sorbite and Carbides. Magnification × 750. Specimen from Steel Containing 2.00 Per Cent Carbon, 13.00 Per Cent Chromium. Etched in Ferric Chloride Plus Nitric Acid.

the composition and the method of etching this steel were known the structure shown in Fig. 100 could easily be mistaken for pure ferrite.

One of the most common of the high carbon, high chromium, die and tool steels is the material containing 2.00 per cent carbon and 13.00 per cent chromium. This steel can be heat treated to produce almost any structure desired. After quenching in oil from 1800 degrees Fahr. it is very hard but due to the excess of carbides present it is brittle and has a low resistance to impact. As typical of the structure of high carbon, high chromium steels after various heat treatments the photomicrographs shown in Fig. 101 to 104 inclusive are reproduced here. The table gives the heat treatment and the resulting structure and hardness.

Fig. No.	Quenching Temperature	How Cooled	Structure of Matrix	Rockwell "C" Hardness
101	2100	Water	Austenite	38
102	1900	Oil	Martensite	65
103	1800	Air	Martensite	62
104	1650	Furnace	Sorbite	29

As the carbon content of this particular steel is very high (2.00 per cent) it is impossible to effect the complete solution of the carbide by heat treatment. It will be noted, however, that in heating to 2100 degrees Fahr. most of these carbides have gone into solution. The specimen shown in Fig. 102 which was quenched from 1900 degrees Fahr. shows many more carbides undissolved, and Fig. 103, heated to 1800 degrees, still more. In the specimen furnace cooled from 1650 degrees Fahr. (Fig. 104) most of the carbides have been thrown out of solution in the slow cooling. It will be noted that there is very little difference in hardness between the oil-quenched specimen and the one cooled in air. This is characteristic of the high chromium steels.

Effect of Vanadium on the Structure of Steel

Vanadium is an element of mystery. It is one of the most powerful of all of the alloying metals; the addition of small amounts (0.15 to 0.30 per cent) affecting the physical properties of the steel to an astounding degree. These small amounts of vanadium when added to molten steel probably go into solution and remain in solid solution in both gamma and alpha iron. Vanadium is most effective when used in combination with chromium; the alloy steel containing 0.20 to 0.50 per cent carbon, about 1.00 per cent chromium, and 0.15 to 0.30 vanadium has wide application as a structural material. This steel resembles the nickel-chromium steels in its response to heat treatment and is frequenty substituted for it as a material for highly stressed parts. Vanadium apparently acts like nickel but is more potent in increasing the strength, elastic limit and hardness with little or no loss in ductility. One of the most valuable characteristics of vanadium is that it inhibits or at least retards grain growth. Most alloy steels containing vanadium are fine-grained and can be heated to higher temperatures than other steels before grain growth and the accompanying embrittlement takes place.

There is no agreement as to the exact effect of vanadium on the structure aside from the inhibition of grain growth. In small amounts it is probably in solid solution and cannot be detected in the microstructure. The steels are pearlitic when slowly cooled and behave in very much the same way as other pearlitic alloy steels in heat treatment except that the resulting physical properties are exceptionally high, higher than almost all other commercial alloy steels

except, perhaps, chromium-molybdenum. A steel containing 0.50 per cent carbon, 1.00 per cent chromium and 0.25 per cent vanadium when quenched from 1600 degrees Fahr. and tempered at 800 degrees Fahr. will have an ultimate strength exceeding 225,000 pounds per square inch, an elastic limit exceeding 200,000 pounds per square inch and an elongation of 12 per cent in two inches. These properties are much better than a 3.00 per cent nickel, 0.75 per cent chromium steel, containing 0.50 per cent carbon quenched and tempered at the same temperature.

Authorities differ widely concerning the cause of the superior physical properties. Some claim that vanadium is a super-scavenger and that the superior properties exhibited by these steels are the result of the removal of oxides, oxygen, nitrogen and other harmful gaseous and liquid impurities in the molten metal by the vanadium. Others maintain that the excellent properties are due to the presence of small amounts of vanadium in solution in the alpha iron which exercise a strengthening effect upon it.

Vanadium in amounts varying from 0.75 to 2.50 per cent is a valuable addition to high speed steel. Just what function it has in this material is uncertain, but it is well established that high speed steel containing 1.00 to 2.00 per cent vanadium is better than the same steel in which it is absent. In high speed steel part of the vanadium is in solid solution; the rest probably reacts with the carbon to form vanadium carbide. Little is known definitely about this carbide, apparently it resembles iron carbide in appearance and properties. It is claimed that it does not go into solution in gamma iron as readily as cementite and does not diffuse as rapidly.

Effect of Tungsten on the Structure of Steel

Tungsten in small amounts has little effect upon the structure and properties of steel. This, coupled with the high cost of the alloy, has prevented its use in structural materials. In large amounts up to 18.00 or 20.00 per cent, and especially when alloyed in conjunction with chromium and vanadium it imparts the property of red-hardness to steel. After the proper heat treatment these high tungsten steels are as hard or harder at a red heat than they are at atmospheric temperature. This makes possible machining speeds unheard of with carbon tool steels. The discovery and development of high speed tool steels containing 13.00 to 20.00 per cent tungsten, 3.00 to

5.00 per cent chromium, 1.00 to 2.00 per cent vanadium and 0.50 to 0.80 per cent carbon has been responsible, more than any other factor, for our present-day industrialized civilization. Because of their great commercial importance as much or more study has been given to high speed tool steels than to any single product of the iron and steel industry. Since the properties and uses of these steels are so well known we will devote but a moment to a brief survey of the structure.

In spite of the vast amount of study which has been given tungsten steels their constitution is not well understood. In the first place tungsten combines with both carbon and iron to form complex chemical compounds consisting of carbides and tungstides of unknown or indefinite composition. It is certain that tungsten combines with carbon to form tungsten carbide, WC; and is very probable that it reacts with iron to form a tungstide which may be either Fe_2W or Fe_3W. Some investigators claim that it forms double carbides of the composition x Fe_3C. y WC, in which x and y vary according to the amount of the carbon and tungsten present. When we recall that chromium and vanadium also form these complex carbides it is at once evident that the structure of high speed and other chromium-tungsten steels may be very complicated.

The effect of tungsten on the structure of carbon steel is shown in Fig. 105. According to this diagram, low carbon steels are pearlitic when slowly cooled if they contain less than 8.00 to 10.00 per cent tungsten. As the carbon increases the maximum amount of tungsten for a pearlitic structure decreases along the sloping line. When the composition falls above this line the slowly cooled steel contains pearlite plus carbides. These carbides are soluble in gamma iron, the degree of solubility varying with the temperature and the time. To harden high speed tungsten steels successfully, temperatures of 2100 to 2300 degrees Fahr. must be used. Since these steels are subject to grain growth at these high temperatures it is necessary to preheat slowly and carefully to a red heat and follow this by a rapid heating to the quenching temperature. The quenching is usually in oil and in the case of high speed steels this is always followed by tempering at approximately 1100 degrees Fahr.

A large proportion of the tungsten steels made is of the high speed grade already described and containing chromium and vanadium in addition to the tungsten. There are three other classes of

tungsten steels used commercially. The low tungsten grade, containing 0.50 to 2.50 tungsten and occasionally 1.00 per cent chromium is used for tools and for the valves (intake) of internal combustion engines. A special grade of tool steel known as semi-high speed or fast finishing contains 1.00 to 1.50 per cent carbon, 2.50 to 5.00 per cent tungsten, about 1.00 per cent chromium and 0.25 per cent vanadium.

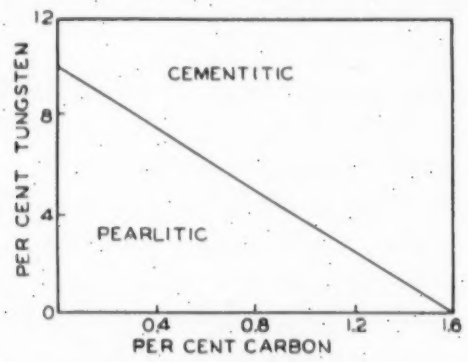


Fig. 105 — Constitutional Diagram of Tungsten Steel. (Guillet)

The third class includes the permanent magnet steels which contain 0.60 to 0.80 per cent carbon and 4.50 to 7.00 per cent tungsten. Much study has been given to the heat treatment of high speed and other tungsten steels and recommended procedures have been worked out for all grades.[86]

Effect of Molybdenum on the Structure of Steel

The constitutional diagram for molybdenum steels is similar to the diagram for tungsten steels shown in Fig. 105. The sloping line extends from 2.50 per cent molybdenum to 1.6 per cent carbon. Low carbon steels containing less than 2.50 per cent molybdenum are pearlitic when slowly cooled. With higher carbon or molybdenum contents the steels are pearlitic with excess carbides present. Molybdenum is soluble in molten carbonless iron and remains in solution in the gamma and alpha iron. The carbide formed when carbon is present has been assigned the formula Fe_3C, Mo_2C, and also $Fe_3Mo_6C_2$.

Molybdenum has been added to replace a part of the tungsten in high speed steels but is rarely used for this purpose now. The commercial molybdenum steels are the structural grades containing

[86]See the Handbook, American Society for Steel Treating.

0.20 to 0.50 per cent carbon, about 1.00 per cent chromium and less than 0.50 per cent molybdenum. In this steel molybdenum behaves in very much the same way as vanadium; only 0.15 to 0.25 per cent is necessary to exercise a marked strengthening of the material, increasing the elastic limit and hardness with little or no loss of ductility. After heat treatment chromium-molybdenum steels have about the same physical properties as chromium-vanadium of approximately the same carbon content. Like vanadium, molybdenum increases the range of quenching temperatures without causing grain growth.

Chromium-molybdenum steels are easily made, and readily forged or rolled. They can be cold-worked satisfactorily and have excellent machining properties. The ease by which they can be welded has resulted in their wide use in the aircraft industry. The fuselage of the modern airplane is constructed almost wholly of the welded chromium-molybdenum seamless tubing. In the structural grade the material is wholly pearlitic when slowly cooled; no excess carbides are present. Quenching in oil or water from 1600 degrees Fahr. produces a fine-grained martensite which tempers uniformly to troostite or sorbite. The pearlitic chromium-molybdenum steels have great future possibilities.

Effect of Other Alloying Elements on the Structure of Steel

There are a few other metals occasionally alloyed with steel which may be mentioned briefly. Silicon is used as an alloying element in steels which must have high magnetic permeability and high electrical resistance, and, commonly, in spring steels. The former contain 3.00 to 4.00 per cent silicon; the latter 1.00 to 3.00 per cent silicon and 0.50 to 0.80 per cent manganese. Both grades are used in the heat treated condition. It is thought that silicon reacts with iron to form iron silicide, FeSi or Fe_2Si, which dissolves in alpha iron. All of the commercial silicon steels are pearlitic when slowly cooled. Since silicon promotes the dissociation of iron carbide, care must be used in annealing high silicon steels to prevent the formation of graphite (temper carbon). This is not likely to occur when the silicon is less than 5.00 per cent.

Cobalt is occasionally added to high speed steel and is now a common constituent of some of the new valves for aircraft engines. These steels contain about 1.25 per cent carbon, 1.00 per cent silicon,

13.00 per cent chromium, 0.90 per cent molybdenum, and 2.50 to 3.50 per cent cobalt. It is claimed that cobalt intensifies the effect of the other elements in resisting oxidation and retaining a high hardness at elevated temperatures. The cobalt-chromium valves are proving very satisfactory. Cobalt probably dissolves in both gamma and alpha iron. In this respect it behaves in much the same way as nickel.

Copper in small amounts, 0.20 to 0.30 per cent, is added to steel to increase its resistance to atmospheric corrosion. Like nickel it dissolves in molten iron and steel and remains in solution at all temperatures. After copper is added to steel there is no way to remove it.

Two other elements, uranium and zirconium have been used as alloys in steel. Too little work has been done on these metals to show whether or not they are of value. There is but little known definitely about the effect of either on the structure or properties of steel.

Conclusion

In the foregoing chapters we have tried to point out the essential facts and the most logical theories underlying the constitution of the iron-carbon alloys. We have looked at the pure alloys, uncontaminated by other elements; and also at the commercial alloys as produced by our iron and steel industry which contain small amounts of the impurities sulphur and phosphorus, and small but varying amounts of the beneficial elements silicon and manganese. We have also glanced briefly at the iron-carbon alloys to which have been added one or more of the alloying metals, nickel, manganese, chromium, vanadium, tungsten, molybdenum, and others. These iron-carbon alloys, pure and impure, simple and complex, have been studied for many years by hundreds of trained men among whom can be included some of the brightest minds known to science. We know a great deal about these alloys; but there is much we do not know.

Throughout the world of steel, workers in the metallurgical sciences are studying the constitution of the iron-carbon alloys trying to clear up conflicting views, trying to reconcile opposing theories, trying to discover the truth. We must not get discouraged if their progress is slow, or if our industrial advance outstrips the forward strides of science. We can harden steel; we can commercialize this, the most important phenomenon known to an industrial civilization, but in spite of all of our skill, in spite of all of our study and our

progress, we do not know why steel behaves as it does when it is cooled rapidly from a bright red heat.

In this series of articles just concluded we have tried to explain as clearly as possible, even at the sacrifice of some accuracy, the known facts and theories regarding the constitution of the iron-carbon alloys and their behavior when they are heated and cooled. If this discussion has helped some to better understand the most fascinating and the most important metallic materials known to man; if it has aroused more than a passing interest in these alloys we will be amply repaid for the effort expended in writing it.

Recommended Practice Committee Releases*

PHYSICAL CONSTANTS OF MAGNESIUM

By Cyril S. Taylor and Junius D. Edwards†

Atomic Weight—Magnesium has the atomic number 12. Its atomic weight is 24.32. The atomic volume is 14.0 cubic centimeters. Magnesium has three isotopes; their mass numbers in order of the intensities of the mass spectrum lines are 24, 25, and 26 ([1]), ([2]).

Crystal Form—Magnesium crystallizes with a hexagonal close packed lattice. The unit cell has the following dimensions ([3]), ([4]): the side of the hexagonal base "A" = 3.22×10^{-8} cm, the height of the hexagonal prism "C" = 5.23×10^{-8} cm. The axial ratio c/a = 1.624.

Density—The density at 20 degrees Cent. of magnesium of varying purity and form is given in Table 1.

Table 1
Density of Magnesium

Purity of Magnesium Per cent	Density at 20 degrees Cent.	Form of Sample	Authority
99.99	1.7388	Extruded bar ⅜ inch in diameter	(5)
99.99	1.7388	Same as above, but annealed 2.5 hours at 400 degrees Cent.	(5)
99.95	1.7381	Extruded bar ⅜ inch in diameter	(5)
99.94	1.7386	Extruded bar ⅜ inch in diameter	(5)
99.90	1.7381	Extruded bar ⅜ inch in diameter	(5)
99.90	1.737	As cast	(6)

No change in density was observed as a result of annealing the purest metal for 2.5 hours at 400 degrees Cent. The density of 99.99 per cent magnesium at and above its melting point has been determined by Edwards and Taylor ([5]). The values are given in Table II. The values given were taken from the complete density curve from 20 to 750 degrees Cent.

The values for density are numerically equal to the specific gravity of the metal when referred to the weight of water at 4 degrees Cent. Magnesium at 70 degrees Fahr. weighs approximately 108.5 pounds per cubic foot (1.7388 × 62.428). In passing from the liquid to the solid state at the freezing point, there is a contraction in volume amounting to approximately 4.2 per cent.

†Research Bureau, Aluminum Co. of America, New Kensington, Pa.

Prepared for the Nonferrous Data Sheet Committee of the Institute of Metals Division of the A. I. M. E. and the Recommended Practice Committee of the A. S. S. T.

The relcases from the Recommended Practice Committee as printed herewith will be included in the next edition of the A. S. S. T. HANDBOOK, which will be published about June 1, 1930.

Table II
Density of Magnesium at and Above Its Melting Point[5]
99.99 Per Cent Purity

Temperature degrees Cent.	Density grams per cc.	Remarks
650	1.642	At melting point, solid (calculated)
650	1.572	At melting point, liquid (extrapolated)
673	1.562	Measured
700	1.544	Interpolated

Table III
Average Coefficients of Expansion of Magnesium[6]

Temperature Range Degrees Cent	Average Coefficients of Expansion per Degree Cent Cast Magnesium	Extruded Magnesium	Average
	$\times 10^{-6}$	$\times 10^{-6}$	$\times 10^{-6}$
20-100	26.1	25.8	26.0
100-200	27.8	27.6	27.7
200-300	29.7	29.5	29.6
300-400	31.6	31.5	31.5
400-500	33.5	33.4	33.4
20-200	27.0	26.8	26.9
20-300	28.0	27.8	27.9
20-400	28.9	28.8	28.8
20-500	29.9	29.7	29.8

Compressibility—The compressibility of magnesium or percentage change in volume with unit change in pressure of 1 megabar (0.987 atmospheres or 14.504 pounds per square inch) is approximately 2.9×10^{-6} at room temperature ([7]).

Thermal Expansivity—According to measurements of the Bureau of Standards by Hidnert and Sweeney ([8]), the average thermal expansivity of cast and extruded magnesium (99.99 per cent purity) is given by the following equation, for the temperature range 20 to 500 degrees Cent., L_o is the original length and L_t the length at temperature, t:

$$L_t = L_o [1 + (24.80t + 0.00961t^2) 10^{-6}]$$

The average expansion coefficients for magnesium for a variety of temperature ranges are given in Table III.

Freezing Point—The value adopted by the Bureau of Standards ([9]) for the freezing point of magnesium is 651 degrees Cent.

Specific Heat—The specific heat is defined as the quantity of heat necessary to raise one gram of a given substance through a temperature of 1 degree Cent. Specific heat varies with temperature, and is usually expressed as a mean or average value over a definite range of temperature. The values for the mean specific heat of magnesium over several ranges of temperature are given in Table IV.

Latent Heat of Fusion—The latent heat of fusion of magnesium, or the heat absorbed in converting a unit weight of the metal from solid to

Table IV
Mean Specific Heat of Magnesium

Temperature, Degrees Cent.	Specific Heat	Authority
−190 to + 17	0.2046	Schimpff [10]
	0.2090	Behn [11]
− 85 to + 20	0.2220	Nordmeyer and Bernouli [12]
− 79 to + 17	0.2284	Schimpff
	0.2311	Brunner [13]
	0.2330	Behn
− 17 to +100	0.2495	Brunner
	0.2460	Voight [14]
150 to 250	0.258	Awberry and Griffiths [15]
250 to 350	0.264	Awberry and Griffiths
350 to 450	0.280	Awberry and Griffiths
450 to 550	0.296	Awberry and Griffiths
550 to 625	0.300	Awberry and Griffiths
650 to 750 (liquid)	0.266	Awberry and Griffiths

liquid at its melting point without changing the temperature is 46.5 gram-calories per gram of metal (83.7 B.t.u. per pound [15]).

Boiling Point—According to Hartmann and Schneider ([16]), the boiling point of magnesium is 1107 degrees Cent.

Vapor Pressure—Vapor pressure values for magnesium at various temperatures are given in Table V. Millar's values are estimated from a boiling point of 1120 degrees Cent.; Hartmann and Schneider's values are based on experimental observations.

Heat of Vaporization—The heat of vaporization of magnesium as determined by Musceleanu ([15]) is 1700 gram-calories per gram of metal (3060 B.t.u. per pound). Values calculated by Richards ([19]), Johnston ([20]), Hildebrand ([21]), and Hartmann and Schneider ([16]), range from 1300 to 1500 gram-calories per gram.

Table V
Vapor Pressure of Magnesium

Temperature, Degrees Cent.	Vapor Pressure millimeters of mercury	Authority
25	1.7×10^{-17}	Millar [17]
300	2.5×10^{-5}	Millar
380	1.1×10^{-3}	Millar
651	2.28	Millar
750	12.	Hartmann and Schneider [16]
800	26.	Hartmann and Schneider
850	49.	Hartmann and Schneider
900	94.	Hartmann and Schneider
950	166.	Hartmann and Schneider
1000	280.	Hartmann and Schneider

Critical Temperature—The critical temperature of magnesium, as calculated by Hartmann and Schneider ([16]), is 1867 degrees Cent.

Thermal Conductivity—The thermal conductivity of magnesium is relatively high, being more than three times that of cast iron. The thermal conductivity of magnesium, or the amount of heat in gram-calories transmitted per second through a plate one centimeter thick per square centimeter of its

Table VI
Thermal Conductivity of Magnesium

Temperature Degrees Cent.	Conductivity	Authority
0-100	0.376	Lorenz [22]
101-250	0.35	Williams [23]
18	0.376	Jones [24]
18	0.34	Archbutt [25]
18	0.38	Flusin[21], Maybrey[27], Guillet[28]

surface when the difference of temperature between the two faces of the plate is one degree Cent., is given in Table VI.

Heat of Combustion—The heat of combustion of magnesium with oxygen was determined by Moose and Parr ([29]) and Frank and Hochwald ([30]) as 146,100 gram-calories per mole (Mg + O = MgO), which is equivalent to 10,800 B.t.u. per pound.

Optical Properties—The reflecting power of magnesium has been determined by Coblentz ([31]) and by Hulburt ([32]). Table VII gives the reflecting power of magnesium at various wave lengths.

Table VII
Reflecting Power of Magnesium

Wave length μ=0.001 mm.	Reflecting Power Per cent	Authority
0.18μ	10.0	Hulburt [32]
0.20	20.0	Hulburt
0.30	36.0	Hulburt
0.38	48.0	Hulburt
0.5	72.0	Coblentz [31]
0.6	73.0	Coblentz
1.0	74.0	Coblentz
1.4	75.0	Coblentz
2.0	77.0	Coblentz
2.5	79.0	Coblentz
3.0	80.5	Coblentz
4.0	83.5	Coblentz
5.0	86.0	Coblentz
6.0	88.0	Coblentz
7.0	91.0	Coblentz
8.0	93.0	Coblentz
9.0	93.0	Coblentz

Electrical Resistivity, Conductivity—Some of the electrical properties of extruded magnesium rod are given in Table VIII. Magnesium has a volume conductivity equal to 38.6 per cent of copper. The mass conductivity is 197.7 per cent of copper.

The constant mass temperature coefficients of resistance for magnesium are give in Table IX.

Electrochemical Equivalent—The electrochemical equivalent for magnesium is the number of grams deposited per second by a current of one ampere or the grams per coulomb. It is equal to the atomic weight 24.32 divided by the valence 2, and the constant 96,500, or 0.12601 milligrams per coulomb. In various units it is as follows:

Electrochemical Equivalent of Magnesium

Unit	Value
Milligrams per coulomb	0.12601
Coulombs per milligram	7.9359
Grams per ampere-hour	0.45364
Pounds per 1,000 ampere-hours	1.0001
Ampere-hours per pound	999.90

Electrolytic Solution Potential—According to standard terminology, magnesium is electronegative to the elements which it replaces in solution; the magnesium going into solution in the form of positive ions leaves the metal

Table VIII
Electrical Properties of Magnesium Rod

According to Taylor and Edwards

Specific Resistivity at 20° C.

Magnesium 99.99% (extruded)	4.4611×10^{-6} ohms/cm³
Magnesium 99.95% (extruded)	4.4699×10^{-6} ohms/cm³
Magnesium 99.90% (extruded)	4.4774×10^{-6} ohms/cm³

Volume Conductivity Compared with Copper

International Annealed Copper Standard	100%
Magnesium 99.99% (extruded)	38.65%
Magnesium 99.95% (extruded)	38.57%
Magnesium 99.90% (extruded)	38.51%

Mass Resistivity

International Annealed Copper Standard	0.15328 ohm (meter-gram)
Magnesium 99.99% (extruded)	0.07753 ohm (meter-gram)
Magnesium 99.95% (extruded)	0.07768 ohm (meter-gram)
Magnesium 99.90% (extruded)	0.07780 ohm (meter-gram)
Aluminum (conductor grade)	0.07640 ohm (meter-gram)

Mass Conductivity

International Annealed Copper Standard	100%
Magnesium 99.99% (extruded)	197.71%
Magnesium 99.95% (extruded)	197.33%
Magnesium 99.90% (extruded)	197.01%
Aluminum (conductor grade)	200.70%

negatively charged, hence the characterization "electronegative." The single potential of magnesium (the normal hydrogen electrode being taken as zero and a solution being employed in which the metal ion concentration is normal) is very difficult to measure experimentally, and the results are not reproducible. Latimer ([33]), from thermal data, has calculated the single potential of magnesium to be: $E^\circ = -2.40$ volts, a value which agrees fairly well with earlier calculated values.

Thermoelectric Power—The thermoelectric power of a circuit of two metals is the electromotive force produced by one degree Centigrade difference in temperature between the junctions. Values of the thermoelectric power of metals with respect to magnesium are given in Table X.

Mechanical Properties—The mechanical properties of pure magnesium, as given by American Magnesium Corporation, are shown in Table XI.

Table IX
Constant Mass Temperature Coefficients of Resistance for Magnesium

Smithsonian Physical Tables (1927)

Temperature, Degrees Cent.	Temperature Coefficient of Resistance	Authority
20	0.0040	Bureau of Standards
25	0.0050	Somerville
100	0.0045	Somerville
500	0.0036	Somerville
600	0.0100	Somerville

Table X
Thermoelectric Power of Metals with Respect to Magnesium

Calculated from Data in Smithsonian Physical Tables
(In Microvolts per degree Centigrade)

Metal	0° C.	20° C.	50° C.
Magnesium	0.00	0.00	0.00
Iron	−14.93	−14.17	−12.99
Gold	− 0.58	− 0.97	− 1.55
Cadmium	− 0.41	− 1.45	− 3.00
Copper	+ 0.88	+ 0.51	− 0.06
Lead	+ 2.22	+ 2.03	+ 1.75
Aluminum	+ 2.98	+ 2.71	+ 2.31
Silver	+14.16	+14.98	+16.22

NOTE: The current flows in the magnesium from the hot junction to the cold when the sign is positive.

Table XI
Mechanical Properties of Pure Magnesium

Process of Manufacture	Condition or Heat Treatment	Tensile Strength Lbs. per Sq. In.	Per Cent Elongation in 2 in.	Per Cent Red. in Area	Prop. Limit Lbs. per Sq. In.	Lbs. per Sq. In. ¼% Extension Under Load	Compressive Strength Lbs. per Sq. In.	Lbs. per Sq. In. Shear Strength	Hardness	
									Brinell 500 kg. Load 10 mm. Ball	Scleroscope
Casting (sand)	As cast	13,000	6	6	500	3000	32,000	14,000	30	20
Extrusion	As extruded	28,000	8	8	1000	6500	45,000	16,000	35	23
Rolling (sheet)	As rolled	25,000	4	5	2500	9500	.....	14,000	40	31
Rolling	Annealed	25,000	5	6	2000	9000	.....	14,000	33	27

References

[1]Dempster, *Science*, 1920, vol. 52, p. 559; International Critical Tables, vol. 1, p. 47.
[2]Dempster, *Physical Revue*, 1921, vol. 18, series 2, p. 415; International Critical Tables, vol. 1, p. 47.
[3]Hull, A. W., *Physical Revue*, vol. 10, series 2, 1917, p. 661.

[4]Hull, A. W., *Journal*, Franklin Institute, vol. 193, 1922, p. 200; International Critical Tables, vol. 1, p. 340.
[5]Edwards, J. D., and Taylor, C. S., *Transactions*, American Institute of Mining and Metallurgical Engineers, vol. 69, 1923, p. 1070.
[6]Bureau of Standards Circular 346, p. 288.
[7]Richards, T. W., *Journal*, American Chemical Society, vol. 37, 1915, p. 1643.
[8]Hidnert, P., and Sweeney, W. T., Bureau of Standards Research Paper No. 29, 1928.
[9]Bureau of Standards Circular 35.
[10]Schimpff, H., *Zeitschrift für Physikalische Chemie*, vol. 71, 1910, p. 257.
[11]Behn, U., *Annalen der Physik* (Drude), vol. 1, series 4, 1900, p. 257.
[12]Nordmeyer and Bernouli, *Berichte der deutschen Physikalischen Gesellschaft*, vol. 5, p. 175.
[13]Brunner, Dissertation, Zurich, 1906.
[14]Voight, W., *Wiedemanns Annalen*, vol. 49, 1893, p. 714.
[15]Awberry, J. H., and Griffiths, E., *Proceedings*, Physical Society of London, vol. 38, 1926, p. 378.
[16]Hartmann, H., and Schneider, R., *Zeitschrift für Anorganische Chemie*, vol. 180, 1929, p. 275.
[17]Miller, R. W., *Journal*, Industrial and Engineering Chemistry, vol. 17, 1925, p. 34.
[18]Musceleanu, C., *Bulletin* de lá cad. Roum., vol. 1, p. 145; Verh. physik. Ges., vol. 14, 1912, p. 1032.
[19]Richards, J. W., Metallurgical Calculations, 1918, McGraw-Hill, New York.
[20]Johnston, J., *Journal*, Industrial and Engineering Chemistry, vol. 9, 1917, p. 873.
[21]Hildebrand, J., *Journal*, American Chemical Society, vol. 40, 1918, p. 48.
[22]Lorenz, *Wiedemanns Annalen*, vol. 13, 1881, p. 442.
[23]Williams, Magnesium Handbook, 1923, p. 31, American Magnesium Corp.
[24]Jones, W. R. D., *Journal*, Royal Aeronautical Society, vol. 30, 1926, p. 743.
[25]Archbutt, S. L., *Metallurgist*, vol. 2, 1926, 26.
[26]Flusin, *Revue de Metallurgie*, vol. 18, 1921, p. 586.
[27]Maybrey, H. J., *Foundry Trade Journal*, vol. 27, 1923, p. 391.
[28]Guillet, L., *Revue de Metallurgie*, vol. 19, 1922, p. 688.
[29]Moose, J. E., and Parr, S. W., *Journal*, American Chemical Society, vol. 46, 1924, p. 2656.
[30]Frank, H. H., and Hochwald, F., *Zeitschrift für Elektrochemie*, vol. 31, 1925, p. 581.
[31]Coblentz, W. W., Bureau of Standards Bulletin, vol. 7, 1911, p. 197.
[32]Hulburt, E. O., *Astrophysical Journal*, vol. 42, 1915, p. 205.
[33]Latimer, W. M., *Journal* of Physical Chemistry, vol. 31, 1927, p. 1267.

WIRE ROPE OR CABLE AND RECOMMENDED PRACTICE FOR ITS USE†

Introduction—Wire Rope is one of the most reliable structural materials which can be used. It has the decided safety feature of indicating, by surface inspection, the number of broken wires, when it should be removed from service, provided corrosion is not a factor. Slings made from wire rope, employing proper fittings, furnish the safest method for handling material.[1]

There are five qualities of wire rope in commercial use as follows:

Grades	Approximate Carbon Content
Iron	.05–.15 per cent
Cast Steel	.30–.60 " "
Extra Strong Cast Steel	.60–.70 " "
Plow Steel	.65–.80 " "
High Grade Plow Steel	.75–.90 " "

There are four standard constructions of wire rope; namely, 6x7, 6x19, 6x37, and 8x19. The figures mean that the rope is composed of 6 strands of

[1]The terms, "Cable" and "Wire Rope," are generally considered to be synonymous, however, when the term "Cable" is substituted for "Wire Rope," it is usually preceded by a descriptive adjective which places it in a more or less definite class; such as, a "Track Cable" on a cableway, "Bridge Cable" as used in suspension bridges, etc.

†Prepared by Dr. H. C. Boynton and A. J. Morgan, John A. Roebling's Sons Co., Trenton, N. J., for the Sub-committee on Wire Rope and Cable. The personnel of the Sub-committee was as follows: B. B. Bachman, Chairman, H. C. Myers, H. Styri, and Dr. H. C. Boynton.

7 wires each, 6 strands of 19 wires, etc. There are, however, many variations in strand construction and the number of wires per strand may vary from 7 to 61 or even more should conditions require them.

To attain the different physical properties required in the various constructions, the individual wires of which a wire rope is composed are specially heat treated and cold drawn after the heat treatment, which produces the necessary toughness and strengths. Any attempt, therefore, to eliminate the effect of service overstraining by annealing or any form of heat treatment, such as is given to chain, would obviously destroy the original properties of the wire obtained by the cold drawing. Such a heat treatment would ruin wire rope.

Qualities of Wire Rope

Iron Rope—Iron Rope is low in strength and soft as compared to steel rope, so consequently will stand little abrasion. It is pliable and tough, but its field is limited to uses where the abrasion is slight and the drums and sheaves are large. It is usually recommended for use on drum types of passenger elevators or for transmission of power by wire rope. It is not adapted to general hoisting or guy ropes. It is generally only furnished in the 6x7 and 6x19 standard construction.

Cast Steel Wire Rope—Although twice the strength of iron rope, cast steel wire rope is, comparatively speaking, a low strength steel hoisting rope and is only suitable for what is termed moderate duty. It is used on freight elevators where the operating tension is relatively low, as track cables on short span cableways, as hoist ropes on slow speed shallow mine installations that are equipped with large drums and sheaves, or as haulage rope under very favorable operating conditions. If the duty be heavy, the stronger and tougher grades of steel should be used.

Extra Strong Cast Steel Rope—This rope is a stronger grade of cast steel and is substituted for cast steel rope where a slight increase in the factor of safety is desirable. In practically all cases the higher strength ropes prove more economical for general service.

Plow Steel Rope—Plow steel rope is made of high strength wire considerably stronger than either the cast steel or extra strong cast steel grades. This rope is well suited for the average hoisting conditions where loads are not excessive, where the sheaves are of normal diameter, and where the abrasion is not too severe. Plow Steel Rope has a general use such as on derricks, mine and coal hoists, cableways, cranes, conveyors, logging ropes, etc.

High Grade Plow Steel—This grade of rope is generally given a trade name by the manufacturers. It is a high strength rope recommended in place of the plow steel grade where the abrasion is severe or the rope is subjected to severe shocks, vibrations, or fatigue stresses. This rope is particularly adapted for severe mine duty, for logging lines, scraper dredge and rigging ropes, heavy cranes, ballast unloader ropes, excavating machinery, etc.

Construction of Wire Rope

Standard Coarse Laid Rope—The 6x7 wire rope construction is called "Standard Coarse Laid Rope." It is made of 6 strands of 7 wires each closed

around a hemp center. It is much stiffer than standard hoisting rope and requires larger sheaves. On account of the smaller number of wires used in the construction of this rope it should be used with a higher factor of safety. The wires used in this rope are so much larger in diameter than in the standard

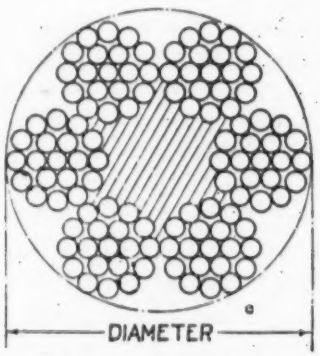


Fig. 1—Construction of 6x19 Wire Rope.

hoisting rope that the rope consequently will stand much more abrasion than a rope made up of smaller wires. This rope is used for heavy haulages with large equipment, wire rope transmissions, tramways, sand lines, etc.

Table 1
Standard Steel Hoisting Rope Plow Steel (6x19)

Diameter in Inches	Approximate Circumference in Inches	Approximate Weight Per Foot	Approximate Strength In Tons of 2000 Lbs.	Proper Working Load In Tons of 2000 Lbs.	Diameter of Drum or Sheave in Feet Advised
2¾	8⅝	11.95	315	63	11
2½	7⅞	9.85	263	53	10
2¼	7⅛	8	210	42	9
2	6¼	6.30	166	33	8
1⅞	5¾	5.55	150	30	8
1¾	5½	4.85	133	27	7
1⅝	5	4.15	110	22	6½
1½	4¾	3.55	98	20	6
1⅜	4¼	3	84	17	5½
1¼	4	2.45	69	14	5
1⅛	3½	2	56	11	4½
1	3	1.58	45	9	4
⅞	2¾	1.20	35	7	3½
¾	2¼	.89	26.3	5.3	3
⅝	2	.62	19	3.8	2½
9/16	1¾	.50	14.5	2.9	2¼
½	1½	.39	12.1	2.4	2
7/16	1¼	.30	9.4	1.9	1¾
⅜	1⅛	.22	6.75	1.35	1½
5/16	1	.15	4.50	.9	1¼
¼	¾	.10	3.15	.63	1

*Standard 6x19 Construction or Standard Hoisting Rope**—This rope is made of 6 strands, each of which is formed by twisting 19 wires together. The

*The 6x19 construction is probably used more often than the others, so much so that it is called "Standard."

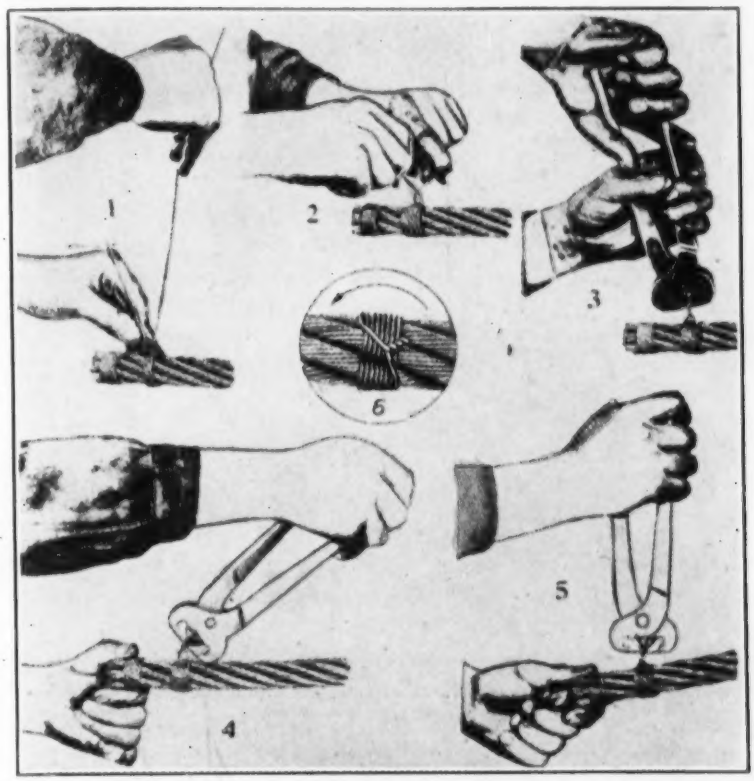


Fig. 2—Applying Servings on a Wire Rope.

1. Wind the serving wire on the rope by hand, keeping the coils together and considerable tension on the wire. 2. Twist the ends of the wire together counterclockwise by hand so that the twisted portion of the wires is near the middle of the serving. 3. Using "Carew" cutters, tighten the twist just enough to take up the slack. Do not try to tighten the serving by twisting. 4. Tighten the serving by prying the twist away from the axis of the rope with the cutters. 5. Tighten the twist again as in (3). Repeat (4) and (5) as often as is necessary to make the serving tight. Cut off the ends of the wires and pound the twist flat against the rope. 6. The appearance of the finished serving.

strands are finally closed around a hemp center. It is generally accepted that rope made with strands having not less than 16 and not more than 31 wires each belong to this general 6x19 class. This rope construction is more generally used for hoisting and other rope uses than all other constructions and is usually considered to be a flexible rope.

Table I gives the important sizes and properties for a Standard Hoisting rope of 6x19 construction made from Plow Steel. This construction is illustrated in Fig. 1.

6x37 Rope Construction—This rope consists of 6 strands, each of 37 wires. When each strand of the rope has not less than 29 or more than 46 wires composing it, the construction is generally considered in this class. This rope construction is generally termed as "Extra Flexible Hoisting Rope" and is usually recommended in place of "Standard Hoisting Rope" when the sheaves are found to be too small for the latter. The wires in this rope are necessarily much

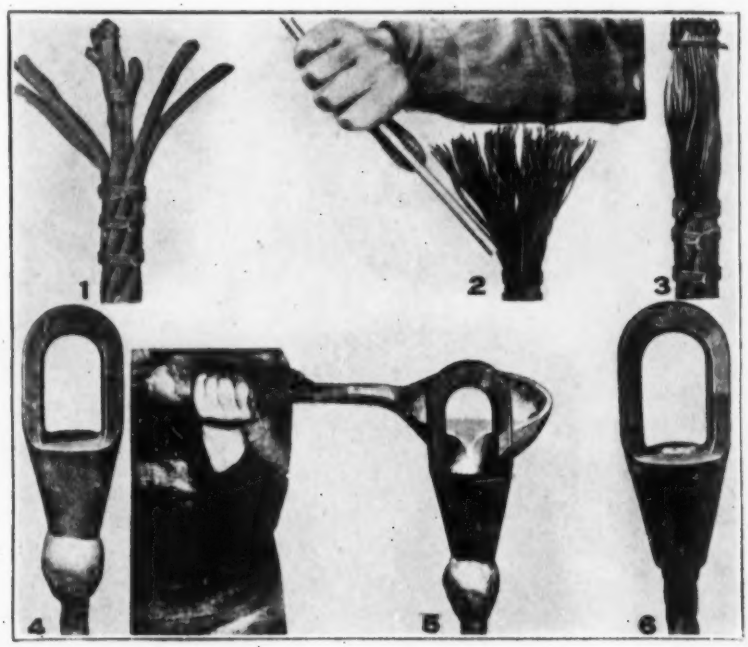


Fig. 3—Socketing Wire Rope.

1. Measure from end of rope a length equal to basket of socket. Serve at this point with not less than three wraps. Cut out hemp center—open strands. 2. Separate wires in strands, straighten by means of iron pipe, cleanse with kerosene oil, wipe dry. 3. Dip wires into one-half muriatic acid, one-half water (use no stronger solution). Keep wires in long enough to be thoroughly cleansed—wipe dry, serve end that socket may slip over all of wires. 4. After placing on socket, cut serving wire at top—have all wires evenly distributed and even with top of basket—place fire clay around bottom of socket. 5. Pour in molten pure zinc—do not use babbitt. 6. Remove all servings except one nearest socket. After cooling it is ready for service.

finer than those used in the standard hoisting rope with 19 wires to the strand and consequently are not as suitable to withstand severe abrasion.

8x19 Rope Construction—This construction is composed of 8 strands of 19 wires each closed around a hemp center. It is generally used where sheaves of small diameter must be employed and the abrasion is light. This rope construction is generally considered to be an "Extra Flexible Hoisting Rope" and sometimes may be considered to be interchangeable with 6x37 rope construction. The metallic area of the 8 strand rope is not so great as the 6 strand rope, but under severe bending conditions the decrease in strength is largely offset by the greater pliability. This rope distorts from its circular cross section more readily than a 6 strand rope so conditions of service which cause crushing require a 6 strand in preference to an 8 strand rope.

Storage—Particular care should be taken in storing wire rope to avoid damage. The rope should be stored in a dry place. It should not be allowed to become so hot as to injure the hemp center. To prevent destructive corrosive action on the steel, the storage place should be free from chemicals or gas from same.

Handling—Care should be taken in handling so that the rope is neither

twisted nor untwisted. Kinks of any nature or the pulling down of loops to small diameters should be avoided. The wires are damaged beyond the elastic limit at such points and in subsequent service will break rapidly, producing a condition which is erroneously termed a bad spot in the wire rope. A spot like this is due to a kink placed in the rope either prior to or during its service.

Cutting—Before the actual cutting operation, proper servings* should always be placed on each side of the point where the rope is to be cut. Such a procedure is absolutely necessary in order to prevent the unlaying or the rotating of the strands. It is advisable to use a minimum of three servings on each side of the cut. The proper method for applying servings is shown in Fig. 2.

Attachments—There are several ways in which the rope ends may be secured. The desirable one, and the one which develops 100 per cent of the rope strength, is a socket connection. The proper method of attaching sockets is shown in Fig. 3.

In preparing the wire for socketing, the hemp center is entirely removed and the "brush" of separated wires is never dipped over three-quarters of its length in the acid so no trouble from corrosion occurs, moreover a slight film of hydrochloric acid acts as a flux to assist the amalgamation of the zinc to the "brush."

A thimble spliced in one end of the rope is often used for an attachment. Its efficiency varies from 75 to 90 per cent of the rope strength, depending upon the rope size. The thimble connection is also used with wire rope clips. This attachment has about the same efficiency as the splice. It is essential, however, in order that maximum efficiency be obtained that the clips be applied one rope lay apart, tightened securely and the U-bolts of the clips always placed on the dead end of the rope. The use of improperly designed clips or improper clip attachments results in strengths as low as 60 per cent of the ultimate strength or less. The thimble is also used with 3-bolt clamps and this efficiency, when the clamps are properly designed, runs about the same or in excess of that obtained by use of clips. Clips and clamps should be tightened after about an hour's run and at the regular inspection intervals after that. It is essential in all of these connections employing the thimble that a proper design of wire rope thimble be used. It should be one which has a sufficient size of eye, and also one which furnishes the proper support to the rope.

Lubrication—The subject of wire rope lubrication is one which should be given careful consideration. Light applications of a comparatively thin oil are usually sufficient for elevator ropes which are not exposed to the elements; while the conditions to be met in a mine shaft require a much heavier lubricant and a protector against the severe inroads of corrosion.

It is not possible for the manufacturers to place sufficient lubrication within a rope to last throughout its entire life. It is essential that a wire rope be lubricated internally as well as externally to reduce internal friction and protection against corrosion. When corrosion starts inside a wire rope its injurious effect can seldom be seen and cannot be arrested before the service and the safety of the wire rope are affected. The lubricant used should preferably be one recommended by the rope manufacturer.

*Servings are sometimes called "seizings," and are merely soft wire fastenings coiled around the rope to prevent unravelling.

The correct lubricant should be one which when applied hot will penetrate thoroughly into the rope and on cooling congeal sufficiently so that it will not drip off, but rather form a plastic coating on the wire. The lubricant should also be free from ingredients which would be injurious to the rope. Improper lubricants which harden on the surface will result in more damage than benefit, because they keep subsequent lubricants out and let in and keep in moisture. This condition accelerates corrosion.

In the American Engineering Standards Committee Paper, dated Feb. 24, 1927, is a set of rules for the selection of wire rope lubricants.

Sheave and Drum Grooves—Improper sheave or drum grooves undoubtedly result in more damage to the wire rope than does any other single factor, so consequently cause irregular and uncertain rope service. It is essential that the grooves be of sufficient size for operating with new ropes when installed. The grooves are generally worn down by service; the degree of wear being dependent upon the radial pressure and the material of which the sheave is made. The grooves wear to the diameter of the worn rope operated over them and consequently become small for the new rope. This causes the new rope to receive extra abrasion and distortion which is very detrimental. Sheaves and drums should be inspected before the installation of the new rope and where the groove diameters have worn to less than 1/32 inch greater than rope diameter the grooves of these sheaves should be replaced or remachined so that the groove diameter will correspond to the following limits:

For ropes ¼ to 1¼ inch diameter; groove should be 1/16 inch greater than rope diameter.

For ropes 1 5/16 to 2½ inch diameter; groove should be ⅛ greater than rope diameter.

Removal of Ropes from Service—It is first necessary to determine the factor of safety to which a rope may safely deteriorate. The importance of this will be appreciated since ropes in some places would not endanger life or property should they break. Breakage in other places would be highly dangerous, so the minimum factor of safety must be set for such installations. In general, ropes which have the outside wires reduced 50 per cent of their diameter by abrasion are likely to break rapidly. With some ropes many wires start breaking before this amount of abrasion is reached. It is, therefore, the number and the distribution of the broken wires together with the amount of abrasion which would indicate the remaining strength of the wire rope. The proper way to count a rope for broken wires is to count the number of such broken wires by strands per rope lay. By rope lay is meant that length of rope in which a strand makes one complete revolution about the rope axis. The worst rope lay counted should be the one on which to base the estimate of remaining strength or on which to base the decision as to whether or not the rope should be removed from service. The rapidity with which broken wires develop indicates the degree of fatigue and where the broken wires develop rapidly the rope should be carefully watched, since it will, undoubtedly, have to be removed soon thereafter.

An estimate of remaining strength or decision as to the safety of the rope

cannot safely be made where corrosion is a factor, due to acid mine waters, corroding gases, etc. When corrosion occurs in a wire rope it is impossible to estimate remaining strength or state that the rope is safe without an actual ultimate strength test of the rope. Should this test prove satisfactory there is no definite assurance that the balance of the rope is equally as good as the piece tested.

Long life for wire rope depends upon:

Proper quality of wire used;
Right construction for installation at hand;
Large sheaves, with proper grooves;
Correct lubricants, applied hot for internal and external lubrication;
Prevention of corrosion;
Careful supervision to prevent "kinking" or "looping" in installation, and overloading in service;
Keeping count of broken wires, looking out for fatigue; and
Eternal vigilance at all times.

THE ENGINEERING INDEX

Registered United States, Great Britain and Canada.

In the preparation of the Engineering Index by the staff of the American Society of Mechanical Engineers some 1700 domestic and foreign technical publications received by the Engineering Societies Library (New York) are regularly searched for articles giving the results of the world's most recent engineering and scientific research, thought, and experience. From this wealth of material the A. S. S. T. is supplied with this selective index to those articles which deal particularly with steel treating and related subjects.

AIRPLANE ENGINES

CASTINGS. Servicing the Aircraft Engineer, A. C. Hardy. *Aircraft Eng. (Lond.)*, vol. I, no. 5, July 1929, pp. 159-163, 11 figs.

Description of plants of Midland Motor Cylinder Co. and Birmingham Aluminum Castings Co. which are used to manufacture castings for airplane engines; total area of 35 acres covered by combined works; special star test piece is run from cupola every 20 min.; new North works handling water-cooled cylinder blocks and East works which handles air-cooled cylinders are described: pressure die-casting plant.

AIRPLANE MANUFACTURE

HEAT TREATMENT. Heat Treatment of Alloy Steels in Airplane Work. C. B. Phillips. *Aviation*, vol. 27, no. 16, Oct. 19, 1929, pp. 781-783, 4 figs.

Description of heat-treatment methods employed by Fairchild Airplane Manufacturing Corp., Farmingdale, L. I., in manufacture of alloy-steel parts for airplanes and engines; analysis of chrome-molybdenum steel-tubing fabricated by welding; chrome-nickel-steel for case-hardening parts; heat treatment of chrome-vanadium steel forging; heat-treating department equipment is also described.

AIRPLANE MATERIALS

STEEL—Uses of Aircraft Steels. *Aircraft Eng. (Lond.)*, vol. 1, no. 2, Apr. 1929, pp. 51-53, 6 figs.

Properties and advantages of various alloy constructional steels employed in airplane manufacture are discussed; great savings that can be effected in judicious choice of appropriate steel for particular part; nickel steel, 0.20 carbon steel, 3 per cent nickel case-hardening steel, oil-hardening nickel chrome steel, 60-ton nickel chrome steel, chrome vanadium steel, valve steels, and nitrogen hardening steels are taken up.

ALLOY STEEL

Alloy Steels, R. Hunter. *Machy. Market (Lond.)*, no. 1510, Oct. 11, 1929, pp. 936 and 940.

Brief description of more common alloy steels met with in general engineering practice; characteristics of plain carbon steel indicated to show advantages of alloying elements; reasons for using high-tensile alloy steels; properties of chromium steel, stainless iron, and nickel steel, nickel-chrome steels, silicon steel and manganese steel.

ALLOY STEEL PROPERTIES

Physical Properties of Pure Chromium and Tungsten Steels (Physikalische Eigenschaften von reinen Chrom und Wolframstaehlen), F. Staeblein. *Archiv fuer das Eisenhuettenwesen (Duesseldorf)*, vol. 3, no. 4, Oct. 1929, pp. 301-305, 10 figs.

Notes on specific gravity, specific resistance, magnetic properties thermal conductivity, and heat expansions of alloys containing about 25 per cent chromium or tungsten.

ALUMINIUM ALLOYS

Corrosion of Aluminum Alloys in Superheated Steam (La corrosion des alliages d'aluminium dans la vapeur d'eau surchauffée), L. Guillet and Ballay. *Metallurgie et Construction Méchanique (Paris)*, no. 44, Nov. 2, 1929, p. 17.

Study of mechanical effects of corrosion; comparison of corrosion of pure aluminum and of three alloys by superheated steam. Read before Académie des Sciences.

Aluminum and Its Alloys, A. G. C. Gwyer. *Metal Industry (Lond.)*, vol. 35, nos. 12 and 14, Sept. 20 and Oct. 4, 1929, pp. 275-278 and 325-326, 8 figs.

Sept. 20: Constitution of some of more important aluminum alloys is considered, including aluminum-copper, aluminum-copper-zinc, and aluminum-silicon; heat treatment of aluminum alloys; precipitation theory; age-hardening alloys. Oct. 4: Discussions of what X-ray spectography has already done for aluminum metallurgy. (Concluded.) Paper presented before Brit. Inst. of Metals.

CEMENTATION. Cementation of Light and Ultra-Light Alloys with Regard to their Protection against Seawater Corrosion (Cémentation des alliages legers et ultra-legers en vue de leur protection contre la corrosion à l'eau de mer), J. Cournot and E. Perot. *Revue de Métallurgie (Paris)*, vol. 26, no. 7, July 1929, pp. 367-374.

Present contribution is supplement to study on cementation of aluminum with copper; influence of nature of deposition;

Photostatic copies (white printing on a black background) of any of the articles listed may be secured through the A. S. S. T. The price of each print, up to 11 by 14 inches in size, is 25 cents. Remittances should accompany orders.

cementation in salt baths; cementation of aluminum and duralumin with ferro-alloys; cementation of aluminum after double electrolytic deposits.

COLD WORKING. Effect of Cold Rolling on Physical Properties of Metals, R. L. Templin. *Rolling Mill Jl.*, vol. 3, no. 9, Sept. 1929, pp. 393-394, 1 fig.

Effects of cold working upon physical properties of aluminum are discussed; rate of strain hardening in cold working indicated by tensile stress; changes in yield point and elongation. Abstract of paper presented before Am. Inst. Min. and Met. Engrs.

HEAT CONDUCTIVITY. Thermal Conductivity of Light Alloys for Pistons, C. Grard and J. Villey. *Iron Age*, vol. 124, no. 16, Oct. 17, 1929, p. 1036, 1 fig.

Influence of copper on conductivity of aluminum and magnesium is shown; alloys of particular value for aircraft engines. Abstract of paper presented before Académie des Sciences.

AUTOMOBILE PLANTS

X-RAY LABORATORIES. Radiographic Analysis of Metals Suitable for Stressed Parts, W. L. Fink and R. S. Archer. *Automotive Industries*, vol. 61, no. 16, Oct. 19, 1929, pp. 571-574, 9 figs.

Description of X-ray laboratory installed at new foundry of U. S. Aluminum Co. at Fairfield, Conn.; field of advantageous use of radiography in metal industry is determined by balancing cost, which is comparatively high, against benefits obtainable through accurate inspection; X-ray apparatus employed was well developed for both diagnostic and deep-therapy medical work; general principles underlying radiography; most of radiographic work has been done on highly stressed parts.

BERYLLIUM

Beryllium—Researches. *Metal Industry (Lond.)*, vol. 35, no. 13, Sept. 27, 1929, pp. 299-301, 1 fig.

Beryllium-copper alloys are taken up; beryllium-copper equilibrium diagram; investigation of nickel and copper alloys with low beryllium contents made by Masing and Dahl discussed; greatest hardness obtained on 2.5 per cent beryllium-nickel alloy quenched from 1100 deg. cent., cold rolled and tempered at 450 deg. cent. for eight hours; beryllium-iron, beryllium-aluminum and beryllium-silicon alloys. (Concluded.) Translated from Beryllium-Arbeiten.

CASTINGS

PROPERTIES. How Castings Meet Designers' Needs in Modern Machinery, D. M. Avey. *Machine Design*, vol. 1, no. 1, Sept. 1929, pp. 26-30, 7 figs.

Various phases of application of castings to machine construction from standpoint of designer; physical properties of castings are listed; properties of gray cast iron and their value to machine designer; malleable cast iron characteristics; steel castings; nonferrous castings.

CAST IRON

Is Cast Iron Becoming Obsolete? R. M. Allen. *Indus. Power*, Nov. 1929, pp. 53-54, 56, 28, 70, 72 and 74, 5 figs.

Recent activity in use of semi-steel and new developments in high-test cast iron have created revived interest; article includes simple non-technical description of cast iron and points out characteristics which distinguish it from steel; melted iron readily dissolves carbon; difference between cast iron and steel; cast iron superior for certain purposes; high strength is recent development.

ALLOY. Alloy Additions Affect Corrosion of Cast Iron, P. Koetzschke, *Foundry*, vol. 57, no. 20, Oct. 15, 1929, pp. 863-866, 14 figs.

Reasons for conclusions derived from data on corrosion and rusting of cast iron are given; silicon plays important part in rust and corrosion resistance of cast iron; nickel additions have favorable effect in some instances and unfavorable in others; chromium has beneficial effect but increases machining difficulties.

ELECTRIC FURNACE MELTING. Electrically Melted Gray Cast Iron (Ueber Elektrograuguss), J. H. Kuester and C. Pfannenschmidt. *Giesserei (Duesseldorf)*, vol. 16, no. 42, Oct. 18, 1929, pp. 969-975, 23 figs.

Information on strength of electrically melted gray iron with high carbon content.

Production of Synthetic Gray Iron in the Electric Furnace (Die Erzeugung von synthetischem Grauguss im Elektroofen), Nathusius. *Giesserei (Duesseldorf)*, vol. 16, no. 43, Oct. 25, 1929, pp. 993-999 and (discussion) 999-1000, 11 figs.

Development of electrosynthetic gray-iron process from process for production of synthetic pig iron in electric furnaces; investigation is made to determine whether relation exists between coefficient of strength and structural constituents on one hand and chemical composition and nature of graphite separation on other hand; method described has been successfully used in foundries of Brown-Boveri Co. and Sulzer Bros.

HEAT TREATMENT. Influence of Heat Treatment on Gray Iron Castings (Influence du traitement thermique sur la fonte grise), Godefroid. *Fonderie Moderne (Paris)*, vol. 23, July 25, 1929, pp. 293-302.

Series of experiments to determine reactions produced on gray cast iron by heat treatment; influence of elements entering into composition of casting on rate of reactions; it is proved that identical heat treatments produce castings similar in hardness and structure; influence of silicon, nickel, manganese, and chromium; to produce castings to resist tensile stresses, it is recommended that they be annealed or aged; Schaap procedure recommended for castings for rapid machining.

CHEMICAL EQUIPMENT

NICKEL-SILICON STEEL. Weak Sulphuric Acid Yields to Nickel-Silicon Steels, W. B. Earnshaw. *Chem. and Met. Eng.*, vol. 36, no. 9, Sept. 1929, p. 536.

Properties of new steel alloy primarily designed for resistance to hot weak solutions of sulphuric acid.

DIE CASTING, ALUMINUM

Advantages of Aluminum as a Foundry Material, G. Mortimer. *Can. Foundrymen (Toronto)*, vol. 20, no. 9, Sept. 1929, pp. 14-17.

Methods of die casting aluminum are discussed, including slush, gravity, centrifugal, cothias, and pressure casting; true die casting; accuracy of dimensions obtained; choice of system; technical and economical considerations.

DIES

WEAR RESISTANCE. Wear Resistance of Dies Studied. *Chem. and Met. Eng.*, vol. 36, no. 10, Oct. 1929, p. 617.

Abrasive action of plastic clay in flowing through dies wears liners rapidly and makes necessary frequent renewals; no data appear to be available showing relative wear values of different metals, such as those used for lining dies; such investigation has therefore been undertaken by United States Government; work includes tests on different kinds of cast iron, steel and bronze.

FORGING. The Construction of Drop Forging Dies, G. A. Smart. *Heat Treating and Forging*, vol. 15, no. 10, Oct. 1929, pp. 1293-1295, 11 figs.

Purposes of fullers and rollers in construction of drop forging dies and methods of application are discussed; fullers and rollers for use in drop forging connecting rods; open rollers or edgers used on forgings of uniform sizes.

MANUFACTURE. Forging Dies Made by Improved Methods. C. B. Phillips. *Iron Trade Rev.*, vol. 85, no. 15, Oct. 10, 1929, pp. 901-903, 5 figs.

Practice employed in die-making division of Studebaker Corp., South Bend, Ind., is described; die blocks are bought annealed, impressions cut, and block heat treated and finished; careful heat treating methods described; daily inspection of dies in use; two distinct methods used in forging crankshaft with these dies outlined; new block steel employed for crankshaft and all heat-treating operations eliminated except normalizing.

ELECTRIC FURNACES

ANNEALING. Anneals Magnetic Sheets Electrically. F. E. Finlayson. *Iron Age*, vol. 124, no. 16, Oct. 17, 1929, pp. 1037-1040, 6 figs.

Advantages over old method of use of elevator furnaces for annealing magnetic steel and other materials are discussed; reducing atmosphere eliminates necessity for boxes and produces bright sheets, without "stickers," having improved magnetic characteristics; reduction in annealing cost per ton; possibility of heavier loading and reduction in annealing time; improvement of working conditions.

ANNEALING. Electric Annealing Plants (Elektrische Gluehanlagen). *Stahl und Eisen (Duesseldorf)*, T. Stassinet, vol. 49, no. 42, Oct. 17, 1929, pp. 1509-1518, 17 figs.

Description of electric hydrogen bright annealing furnace installation; data on production and current requirement; electric black annealing plant and its advantages due to low heat storage; comparison of two plants; general rules for bright annealing installations; experimental results.

FOUNDRY. 500 Kw.-Hr. per Ton for Steel Castings, D. T. Waby. *Elec. World*, vol. 94, no. 12, Sept. 21, 1929, p. 574.

Steel foundry in Middle West melted more than 23,000 tons of steel in one furnace in three years with average consumption of 500 kw.-hr. per ton; author points out that average charge per heat was 5.8 tons and average time between heats 10.2 min.; table showing three years' record of large electric steel foundry.

HEAT TREATING. Heat Treatment and Production Costs, A. N. Otis. *New England Indus. Elec. Heating Conference—Proc.*, June 1929, pp. 48-52, 3 figs.

Rating hearth furnace; elevator-type electric furnace; pusher-type electric furnace using hydrogen atmosphere; composition of atmosphere in furnace for annealing sheet and uses to which electric furnaces are or may be adapted for improvement of heat-treated products and reduction of cost, are discussed.

HEAT TREATING. Electrically Heated Hardening and Tempering Baths Compared with Fuel Methods of Heating, W. S. Scott. *Am. Soc. Mech. Engrs.—Advance Paper*, for mtg. Oct. 7 to 10, 1929, 7 pp., 8 figs.

Necessity for uniform products and improved working conditions led Warren Axe and Tool Co. to replace its fuel-heated furnaces with electrically heated types; reduction in costs of manufacture has also resulted, so that, based on actual book profit, new equipment will pay for itself in 18 months; new equipment, its control and operation, are described.

HIGH FREQUENCY. High Frequency or Coreless Induction Furnaces. *Metallurgist (Supp. to Engineer, Lond.)*, Sept. 27, 1929, pp. 135-136, 2 figs.

Notes on design utilization; drawings are given for complete furnace equipment, and it is recommended that generator should be placed near furnace for economy and to permit of its ready supervision by furnace staff; efficiency of coreless or high-frequency furnaces as compared with arc furnaces; results are given for number of both types. Review of papers by M. Tama and H. Neuhauss appearing in *Stahl und Eisen*, April 11, and May 9, respectively.

INDUCTION. Coreless Induction Furnaces (Les fours à induction sans circuit ferromagnetique), M. Gliksman. *Revue Générale de l'Electricité (Paris)*, vol. 26, no. 10, Sept. 7, 1929, pp. 361-370, 5 figs.

Influence of frequency of supply current on efficiency and capacity is studied; it is shown in mathematical developments, that for induction furnaces of sufficient power, commercial frequencies are favorable.

RESISTANCE. Tests of Steinberg-Granolin Electric Furnace, A. I. Balandin. *Journal Russkovo Metallurgicheskovo Obshchestva (Leningrad)*, no. 2, 1929, pp. 228-287, 8 figs.

Description of first metallurgical electric furnace invented and manufactured in Russia; furnace is of resistance type; tests included with determinations of temperature, analysis of gas and metals, etc.; heat bal-

ance; losses of electric current; efficiency coefficient.

STEEL MAKING. Steel Melting in Induction Furnaces, F. J. Cox. *Elec. Times (Lond.)*, vol. 76, no. 1980, Oct. 3, 1929, pp. 496-498, 4 figs.

Development of coreless-induction furnaces marks new era in electric steel melting; various makes of Sheffield Steel Works, Edgar Allen & Co.'s Works, Sheffield, and Metropolitan-Vickers Works are illustrated; table showing electric power consumption for various types of charge, time input and temperature is given.

STEEL MAKING. Electric Furnace Found Ideal for High-grade Steel Castings, D. Zuege. *Elec. World*, vol. 94, no. 18, Nov. 2, 1929, pp. 880-882, 3 figs.

Casting production based on advantages of electric melting and annealing; close control of metal analyses and treatment permits making of desired alloys; typical annealing temperature chart, showing two charges.

FORGINGS, STEEL

The Effect of Reduction from Ingot to Forging in Steel Forgings, L. H. Fry. *Am. Soc. Testing Matls.—Reprint from Proc.*, vol. 29, pt. 2, 1929, 11 pp., 8 figs.

Summary of investigations carried out by sub-committee of Committee A-1 on steel to ascertain how properties of steel forgings are affected when variation is made in amount of reduction between ingot and forging; work done by other investigators is considered; it is concluded that it is unnecessary to specify amount of reduction to be made between ingot and forging, but that in specifications for blooms requirement of three to one reduction from ingot to bloom may be justified.

FURNACES

ANNEALING. Open-Annealing Furnaces, W. J. May. *Mech. World (Lond.)*, vol. 86, no. 2231, Oct. 4, 1929, p. 316.

Before furnace for open annealing can be laid down it is necessary that exact results which are to be secured in parts treated should be known; structure of metal altered by annealing; effect of some fuel impurities on metals being annealed; construction of open annealing furnaces explained; slabs for lining; provision against expansion which causes arches to drop; gas-heated annealing ovens.

ANNEALING, CONTINUOUS. Modern Annealing Furnaces for Continuous Production in Automobile Plants (Neuzeitliche Gluehoefen fuer Fliessende Fertigung in Motorfahrzeugfabriken), H. Reiniger. *Automobiltechnische Zeit. (Berlin)*, vol. 32, no. 23, Aug. 20, 1929, pp. 506-509, 16 figs.

Main requirements of annealing furnaces for continuous production are characterized, and few types are described which have proved satisfactory.

FORGING; GAS. Semi-Automatic Forging Furnaces, J. B. Nealey. *Heat Treating and Forging*, vol. 15, no. 10, Oct. 1929, pp. 1343-1344, 2 figs.

Description of automatic gas furnace in which small parts are economically heated for forging and treating; furnace is provided with gravity feed and lever by means of which bits are fed into heating chamber one at a time; bits are hardened without reheating.

GAS. Some further Notes on Gas and Air Blast Apparatus, H. R. Hems. *Gas World (Lond.)*, vol. 91, no. 2355, Sept. 21, 1929 (Supplement), pp. 11-15, 9 figs.

Direct fired furnaces; surface combustion type oven furnace; recuperative furnaces; recent design of oven furnace; regenerative types; method of operation; high speed steel furnaces; forging furnaces.

HEAT TREATING. Burning of Iron in Heat Treating Furnaces, N. Y. Teitz. *Journal Russkovo Metallurgicheskovo Obshchestva (Leningrad)*, no. 2, 1929, pp. 288-326, 10 figs.

Study of German and Russian data on laws of weight of iron and ferrous alloys in heat-treating process by oxygenation, etc.

HEAT TREATING—CONVEYORS. Thirteen Classes of Mechanisms Convey Metal Through a Furnace, E. G. de Coriolis. *Iron Age*, vol. 124, no. 15, Oct. 10, 1929, pp. 960-962, 5 figs.

Description of reliable mechanisms for conveying metals through heat-treating furnaces; conveyor belt for use in heat treatment of small parts; rotary-hearth furnaces combine many advantages not possessed by other types; rotary cylinders; limitations of spiral.

FURNACES, INDUSTRIAL

DESIGN. Industrial Furnace Technique, A. Hermansen. Lond., E. Benn, Ltd., 1929, 25 shillings. Reviewed in *Chem. and Industry (Lond.)*, vol. 48, no. 43, Oct. 25, 1929, p. 1039.

Opening with historical account of theory of heat and development of furnace building, author proceeds to discuss combustion and calorific values; production of high temperatures with fuels, carbonization, and producer gas; transmission of heat, movement of hot gases; burners, draft openings, working chambers, and calculations relating to working space as well as materials available for furnace construction.

OIL FIRED. Fuel Oil For Industrial Furnaces, L. D. Becker. *Am. Soc. Mech. Engrs.—Advance Paper*, for mtg. Oct. 7-10, 1929, 5 pp.

Improved designs in furnaces that have resulted in oil-fuel economy; types of furnaces in which oil is used as fuel; advantages of oil fuel.

REVERSED FLAME. Laboratory Furnaces with Flame Circulation Guaranteeing Uniform Temperature from Hearth to Arch (Fours à circulation des flammes au laboratoire, etc.), V. E. Grum-Grzhimailo. *Revue de Métallurgie (Paris)*, vol. 26, no. 7, July 1929, pp. 358-363, 6 figs.

It is claimed that chamber furnaces, correctly fed by flames emitted from flues, and operating on reversed-flame principle, result in ideally uniform temperature in horizontal design; system has been employed in various industrial applications, including ceramic kilns, heat-treating furnaces, etc.

FURNACES, MELTING

OIL-FIRED. Study Furnace Reactions,

H. Illies. *Foundry*, vol. 57, no. 21, Nov. 1, 1929, pp. 922-924, 6 figs.

Results of experiments conducted in German foundry employing oil-fired furnace to mix and superheat molten blast-furnace and cupola irons; test bars cast every 15 minutes from oil-fired reverberatory furnace give some interesting data on changes during superheating of mixed blast furnace and cupola irons; losses in elements of iron are slight, but increase is evident in physical properties. Translated from Giesserei, Mar. 30, 1928.

PULVERIZED COAL. Materials and Heat Balances of Some Charges in the Brackelsberg Furnaces (Stoff und Waermebilanzen einiger Schmelzungen im Brackelsbergofen), P. Bardenheuer and K. L. Zeyen. *Mitteilungen aus dem Kaiser-Wilhelm-Institut fuer Eisenforschung zu Duesseldorf*, vol. 11, no. 14, 1929, pp. 237-246, 7 figs. See also *Stahl und Eisen (Duesseldorf)*, vol. 49, no. 39, Sept. 26, 1929, pp. 1393-1398, 6 figs.

Metallurgical characteristics of melting process are discussed; determination of bases for materials and heat balances of two malleable-iron charges and one cast-iron charge; evaluation of results.

PULVERIZED COAL. The Importance of the Brackelsberg Furnace for the Iron Foundry, P. Bardenheuer. *Foundry Trade Jl. (Lond.)*, vol. 41, nos. 682 and 683, Sept. 12 and 19, 1929, pp. 191-193 and 210-211 and (discussion) 211, 3 figs.

Sept. 12: Applications of coal-dust rotary furnace for production of high-grade gray-iron castings; gas absorption minimized; differences from cupola practice; character of iron melted; high-temperature and quality castings; 28 tons tensile strength, obtained; malleable-iron melting; increasing use of steel scrap; applying research results. Sept. 19: Applications to melting of malleable iron; melting costs; piping reduced; high elongation for malleable. Translated from *Giesserei*.

FURNACES, METALLURGICAL

Furnaces for the Metal Industry at the Leipzig Fair of 1929 (Oefen fuer die Metallindustrie auf der Leipziger Fruehjahrsmesse 1929), H. Reininger. *Maschinenbau (Berlin)*, vol. 8, no. 17, Sept. 5, 1929, *(Betrieb)*, pp. 569-580, 48 figs.

Annealing, forging, and hardening furnaces; furnaces for continuous production; salt-bath furnaces and equipment for special purposes; improvement of efficiency and economy through progress in design are noted.

FURNACES, NITRIDING

World's Largest Nitriding Furnace. *Iron Age*, vol. 124, no. 17, Oct. 24, 1929, pp. 1102-1103, 6 figs.

Description of what is said to be largest nitriding furnace in world which has been constructed by Central Alloy Steel Corp., Canton, Ohio, for process of hardening steel with ammonia gas; over two tons can be treated with ammonia gas; products 11 ft. long hardened in it; fan located in box to insure circulation of gas throughout work.

GALVANIZING

Pickling Principles in Galvanizing, W. G. Imhoff. *Iron Age*, vol. 124, no. 15, Oct. 10, 1929, pp. 957-959, 3 figs.

Results of test in pickling and galvanizing water pails; conditions affecting steel surfaces; rolling sheet bars out into sheets; doubling sheets into packs; putting finish on black plate; rolling sheets without using heat; different results from annealing; making pails from annealed sheets; pickling tests proved that the longer the pickling time, the heavier will be the zinc coating deposited.

HARDNESS TESTING

A Synopsis of the Present State of Knowledge of the Hardness and Abrasion Testing of Metals with Special Reference to the Work Done During the Period 1917-27, and a Bibliography, G. A. Hankins. *Instn. Mech. Engrs.—Jl. (Lond.)*, no. 2, Mar. 1929, pp. 317-373 and (discussion) 374-387, 4 figs.

Synopsis covers following tests; Brinell, diamond indentation, steel cone indentation; Haigh prism; Herbert pendulum hardness, dynamic indentation; abrasion or wear, diamond scratch hardness, Hertzian hardness, magnetic hardness.

"Cloudburst" Hardness Testing. *Iron and Steel Industry (Lond.)*, vol. 3, no. 1, Oct. 1929, p. 28, 2 figs.

Latest improvements and modifications adopted in applying Cloudburst method for hardness testing are given; test is applied to whole surface of many articles simultaneously; hardening is effected by same machines and is continuation of same process as that used in hardness testing.

BRINELL. Brinell Testing, R. G. Batson and S. A. Wood. *Times Trade and Eng. Supp. (Lond.)*, vol. 25, no. 590, Oct. 26, 1929, p. 142.

Review of report issued by Department of Scientific and Industrial Research, who were requested to make such investigations as might be necessary to enable specifications to be drawn for hardness of balls used in Brinell testing; work was carried out at National Physical Laboratory; authors draw conclusions by which upper limits of hardness are assigned to application of Brinell testing.

HIGH SPEED STEEL

Report of Research Committee on the Effect of Tin and Arsenic on High-Speed Tool Steel. *Am. Soc. Testing Matls.—Reprint from Proc.*, vol. 29, pt. 1, 1929, 5 pp.

Report gives composition of various high-speed steels and results of testing of two types which show among other things arsenic and tin in amounts of 0.50 per cent in high-speed steel noticeably embrittles steel; hardness of annealed steel is comparable to that of regular high-speed grade.

HIGH-SPEED STEEL BRITTLENESS

Improvement of Viscosity of High-Speed Steel by Carbide Annealing (Verbesserung der Zaehigkeit von Schnellarbeitsstahl durch Karbidgluehung), R. Hohage and R. Rollett. *Archiv fuer das Eisenhuettenwesen (Duesseldorf)*, vol. 3, no. 3, Sept. 1929, pp. 233-239, 29 figs.

Tests were carried out to determine cause of frequently unexpected degree of brittleness of high-speed steel; relation between nature of carbide separation or final temperature of hot working; Brinell hardness and viscosity in relation to heat-treatment process.

IRON

Eisen (Iron), Being System No. 59 of Gmelin's Handbook of Inorganic Chemistry. Berlin, Verlag Chemie, G.m.b.H., 226 pp., 33 marks. Reviewed in *Metallurgist (Supp. to Engineer, Lond.)*, Sept. 27, 1929, p. 143.

Issue deals first with historical questions affecting iron, treatment consisting mainly of very full list of publications dealing with branches of subject, arranged under various races of countries concerned; largest section deals with occurrence of iron both as regards geographical location and nature of iron-bearing minerals.

BRITTLENESS. Fracture of Iron at Low Temperatures (Ueber den Bruchvorgang in Eisen bei tiefen Temperaturen), F. Sauerwald and K. A. Pohle. *Zeit. fuer Physik (Berlin)*, vol. 56, nos. 7-8, July 29, 1929, pp. 576-578, 1 fig.

Report on experimental study, by Department of Metallurgy of Breslau Institute of Technology, on nature of brittleness of iron at temperatures between zero and minus 170 deg. cent.

CARBONIC ACID EFFECT. Action of Carbonic Acid under High Pressures on Iron (Ueber die Einwirkung von Kohlensaeure unter hohem Druck auf metallisches Eisen), E. Mueller and H. Henecka. *Zeit. fuer Anorganische u. Allgemeine Chemie (Leipzig)*, vol. 181, no. 1-2, June 28, 1929, pp. 159-171, 2 figs.

Under high pressures of carbon dioxide, e.g., 20-50 atmos., carbonic acid reacts on aqueous suspensions of metallic iron to produce soluble ferrous hydrogen carbonate; as concentration of hydrogen carbonate ion increases, hydrogen-ion concentration of medium decreases and rate of dissolution of iron approaches zero.

OXYGEN SOLUBILITY. Solubility of Oxygen in Solid Iron (Ueber die Loeslichkeit des Sauerstoffs im festen Eisen), W. Krings and J. Kempkens. *Zeit. fuer Anorganische und Allgemeine Chemie (Leipzig)*, vol. 183, no. 3, Oct. 2, 1929, pp. 225-250, 3 figs.

Report on theoretical and experimental study of solubility of oxygen in solid iron at 715 deg cent., made at Department of Theoretical Metallurgy and Physical Chemistry of Aachen Institute of Technology; equilibrium studies of iron oxide with hydrogen and iron with steam.

IRON ALLOYS

ANALYSIS. The Analysis of Carbon in Iron and Iron Alloys, N. A. Ziegler. *Fuels and Furnaces*, vol. 7, no. 10, Oct. 1929, pp. 1621-1622, 2 figs.

Discussions of relationship between magnetic properties and carbon content of iron-silicon alloys; description of vacuum furnace employed. Abstract of paper presented before Am. Electrochem. Soc.

METALLOGRAPHY. Binary System Iron-Boron and Iron-Beryllium, with a Contribution to the Knowledge of the Binary System Iron-Aluminum (Ueber die Zweistoffsysteme Eisen-Bor und Eisen-Beryllium, mit einem Beitrag zur Kenntnis des Zweistoffsystems Eisen-Aluminium), F. Wever and A. Mueller. *Mitteilungen aus dem Kaiser-Wilhelm-Institut fuer Eisenforschung zu Duesseldorf (Duesseldorf)*, vol. 11, no. 12, 1929, pp. 193-223, 91 figs. partly on supp. plates.

Position of elements boron and beryllium in system of iron alloys is discussed; history, thermal and metallographic analysis, etc., of both alloys are given, as well as those of system iron-aluminum.

IRON ANALYSIS

SPECTROGRAPHIC. Use of Spectrographic Analysis in Iron Metallurgical Laboratory (Die Anwendung der spektrographischen Analyse im Eisenhuettenlaboratorium), K. Kellerman. *Archiv fuer das Eisenhuettenwesen (Duesseldorf)*, vol. 3, no. 3, Sept. 1929, pp. 205-210 and (Discussion) 210-211, 5 figs.

General notes on application of spectrographic analysis; fundamental phenomena for quantitative analysis; description of methods in common use; use of solid and liquid samples; special methods for iron and steel plant laboratories.

IRON CASTINGS

SHRINKAGE. Shrinkage of Iron (Die Schwindung des Eisens). *Zeit fuer die Gesamte Giessereipraxis (Berlin)*, vol. 50, no. 36, Sept. 8, 1929, pp. 311-312.

Shrinkage is caused mainly by silicon, manganese, phosphorus, and silicon, but cooling conditions are also influential; means of prevention are discussed.

SPECIFICATIONS. Standard Specifications for High-Test Gray-Iron Castings. *Am. Soc. Testing Matls. Standards—Supp.*, 1929, pp. 71-72.

Specifications cover: scope; basis of purchase; process; transverse and tension tests; test specimens; number of tests; requirements; finish; inspection.

IRON CORROSION

Influence of Depolarisation on Speed of Rusting and its Practical Application (Der Einfluss der Depolarisation auf die Rostgeschwindigkeit und ihre praktische Nutzanwendung), F. Toedt. *Korrosion u. Metallschutz (Berlin)*, vol. 5, no. 8, Aug. 1929, pp. 169-174.

Corrosion of iron depends on depolarizing action of oxygen; possibility arises that by measuring strength of electric current passing between two metals having different electropotentials and dipping in same solution corrosion of less noble metal may be determined; simple method for measuring corrosion of iron is described.

IRON-CARBON ALLOYS

Influence of Silicon on the Iron-Carbon-Phosphorus System (Der Einfluss des Siliziums auf das System Eisen-Kohlenstoff-Phosphor), O. V. Keil and R. Mitsche. *Archiv fuer das Eisenhuettenwesen (Duesseldorf)*, vol. 3, no. 2, Aug. 1929, pp. 149-156, 22 figs.

Characteristic tendency of sub- and super-eutectoid cast-iron alloys to metastable or stable solidification is pointed out; influence of cooling velocity and alloy additions; investigations of displacement of curve in ternary diagram of state, iron-carbon-phosphorus, by about 1.2, 1.8, and 2.8 per cent silicon; simplified etching process with neutral sodium picrate on phosphide is described.

Influence of the Alloying Elements, Phosphorus, Silicon, and Nickel on the Solubility of Carbon in Molten Iron (Ueber den Einfluss der Legierungselemente Phosphor, Silizium und Nickel auf die Loeslichkeit des Kohlenstoffs im fluessigen Eisen), K. Schichtel and E. Piwowarsky. *Archiv fuer das Eisenhuettenwesen (Duesseldorf)*, vol. 3, no. 2, Aug. 1929, pp. 139-147, 19 figs. See also *Stahl und Eisen (Duesseldorf)*, vol. 49, no. 37, Sept. 12, 1929, pp. 1341-1342.

Determination of displacement of curve of iron-carbon diagram by silicon, phosphorus, and nickel as well as silicon and nickel; change of eutectoid temperature and carbon concentration.

IRON-COPPER ALLOYS

Relation between Hardness and Magnetic Properties of Alloys (Ueber den Zusammenhang zwischen Haerte und magnetischen Eigenschaften von Legierungen), A. Kussmann and B. Scharnow. *V. D. I. Zeit. (Berlin)*, vol. 73, no. 38, Sept. 21, 1929, p. 360, 3 figs.

Abstract of previously indexed papers published in *Zeit. fuer Anorganische und Allgemeine Chemie (Leipzig)*, Jan. 22, 1929, and in *Zeit. fuer Physik (Berlin)*, Mar. 21, 1929.

IRON-NICKEL ALLOYS

Tests of Stability of Hysteresis of Iron Nickel-Alloys (Versuche ueber die Stabilitaet der Hysteresis Fe-Ni-Legierungen), G. Gossels. *Zeit. fuer Anorganische und Allgemeine Chemie (Leipzig)*, vol. 182, nos. 1-2, Aug. 7, 1929, pp. 19-27, 9 figs.

Results of experimental study made at Metallurgical Laboratory of Charlottenburg Institute of Technology; resistance isotherms for temperatures of 0 to 900 deg. cent. and nickel content up to 46 per cent.

IRON-SILICON ALLOYS

The Changes in Physical Properties of Iron-Silicon-Carbon Alloys Produced by Various Heat Treatments, T. D. Yensen. *Fuels and Furnaces*, vol. 7, no. 10, Oct. 1929, pp. 1613-1614, 4 figs.

Discussion of magnetic properties and various annealing and cooling phenomena of iron-silicon-carbon alloys. Abstract of paper presented before Iron and Steel Inst.

IRON AND STEEL

ALUMINUM COATINGS. Heat Resistance of Steel and Gray Cast Iron with Aluminum Surface Treatment (Hitzebestaendigkeit von aluminiertem Stahl und Grauguss), W. Zimm. *Archiv fuer Waermewirtschaft (Berlin)*, vol. 10, no. 8, Aug. 1929, pp. 275-278, 12 figs.

Surface treatment of steel and cast iron according to "Alumetier" process is described; results of tests to determine resistance of such treated parts; influence of resulting coating which is really thin layer of iron-aluminum alloy.

CORROSION. Early Obsolescence May Dictate Common Iron and Steel, E. L. Chappell. *Chem. and Met.*, vol. 36, no. 9, Sept. 1929, pp. 540-541.

Brief discussion of water and oxygen corrosion, high temperature and oxygen corrosion, and chemical corrosion.

HEAT TREATMENT. Effect of deformation on the Transformation Points of Iron and Steel. Ueber die Beeinflussung der Umwandlungspunkte von Eisen und Stahl durch Verformung), F. Sauerwald and T. Sperling. *Zeit. fuer Physik (Berlin)*, vol. 56, nos. 7-8, July 29, 1929, pp. 544-547, 2 figs.

Report from Department of Metallurgy of Breslau Institute of Technology on results of experimental study, in which temperatures up to 940 deg. Cent. were used.

MANGANESE DETERMINATION. Determination of Manganese in Steel and Iron by the Persulphate Arsenite Method, H. A. Bright and C. P. Larrabee. *U. S. Bur. Standards—Jl. of Research*, vol. 3, no. 4, Oct. 1929, pp. 573-579.

Advantages of using phosphoric acid in persulphate arsenite method and effect of certain dissolved salts in titration of permanganic acid by sodium arsenite are discussed; description is given of persulphate arsenite method as used at Bureau of Standards; results obtained by this procedure are much better than those obtained on smaller samples by ordinary persulphate method and are practically of same order of accuracy as obtained by standard and much more elaborate bismuthate method.

PROTECTIVE COATINGS. Rustproofing Processes. *Am. Mach.*, vol. 71, no. 17, Oct. 24, 1929, p. 713.

Description of process employed in parkerizing, sherardizing, and calorizing iron and steel to protect their surfaces from rusting.

MAGNESIUM ALLOY CASTINGS

A Note on Magnesium Alloy for Castings, E. Player. *Aircraft Eng. (Lond.)*, vol. 1, No. 5, July 1929, pp. 175-178, 5 figs.

Properties and practical processes in production of magnesium alloy castings are discussed with special reference to Elektron; foundry practice in regard to melting, molding, and core making of magnesium alloys castings; trimming; machine-shop practice; protection against corrosion; die-castings.

Melting and Casting Magnesium, W. E. Warner. *Metal Industry (Lond.)*, vol. 35, no. 9, Aug. 30, 1929, p. 203.

Precautions necessary in melting and casting magnesium are discussed; necessity for covering with flux while molten; when melting, internal surface for crucible should be dressed internally with wash of French chalk.

MAGNESIUM ALLOYS

ELEKTRON. Elektron Sheet (Ueber Elektronbleche). *Zeit. fuer die gesamte Giessereipraxis (Berlin)*, vol. 50, no. 38, Sept. 22, 1929, pp. 151-152.

It is claimed that elektron, with specific gravity of 1:8, is lightest commercial metal; its basic alloy is magnesium, which is improved by additions of aluminum, zinc, and other metals; article deals especially with properties of elektron sheet in thicknesses of 0.3 to 10 mm., taking into consideration standards established by Committee for Technical Aluminum Alloys.

MALLEABLE IRON

La fabrication de la fonte malleable, C. Busquet. Paris, Dunod, 1929, 158 pp., illus., diagrs., 35, 50 fr.

General account of physical and chemical properties of malleable cast iron, of principal methods of manufacture and of important characteristics of malleable castings; book intended for inspector or buyer of castings, rather than for metallurgist and treats subject from point of view of former. Eng. Soc. Lib., N. Y.

MALLEABLE IRON CASTINGS

Metallurgical Principles Underlying the Production of High-Grade Malleable Castings (Die metallurgischen Grundlagen zur Erzeugung eines hochwetigen Tempergusses), R. Stotz. *Giesserei (Duesseldorf)*, vol. 16, no. 36, Sept. 6, 1929, pp. 839-845, 14 figs.

Metallurgical advantages and disadvantages in melting of malleable iron in crucible, open-hearth furnace, electric furnace, cupola and reverberatory furnace; metallurgical principles underlying tempering and its advantages over expensive cementation.

Malleable Cast Iron, C. H. Plant. *Iron and Steel Industry (Lond.)*, vol. 3, no. 1, Oct. 1929, pp. 25-27.

Tests which every good black-heart malleable casting should pass;; specification laid down by British Engineering Standards Association; foundry costing; system employed for several years is outlined; cost of annealing; means introduced for considerably improving toughness, strength and general quality of malleable castings, is effected by additions of vanadium-titanium iron.

ANNEALING. Shortens Malleable Anneal. *Foundry*, vol. 57, no. 19, Oct. 1, 1929, pp. 825-826, 3 figs.

Results of investigations conducted by General Electric Co. to learn something of mechanism of carbon precipitation with view of possible shortening of process; high temperature with quick drop to 740 deg. cent. decreases heat-treating interval to 28 or 30 hours.

MANGANESE STEEL

Maurer Manganese Steel in the Development of Stainless Steel (Der Maurersche Manganstahl in der Entwicklung der nichtrostenden Staehle), E. Maurer. *Stahl und Eisen (Duesseldorf)*, vol. 49, no. 34, Aug. 22, 1929, pp. 1217-1220, 3 figs.

Review of Brearley's and Haynes' work; priority of German work is emphasized; Guillet and Strauss steels; Borchers-Monnartz patent, and work of Friend, Bentley, and West; general status of knowledge of steel during years 1908-1912; heat treatment of martensitic and austenitic highly alloyed chromium-nickel steels based on 2 per cent Maurer manganese steel.

Hadfield's Steel (L'acier Hadfield), V. N. Svetchnikoff. *Revue de Métallurgie (Paris)*, vol. 26, no. 8, Aug. 1929, pp. 401-408, 14 figs.

Study of physical properties in relation to microstucture and heat treatment of Hadfield's manganese steel, composed of 1.23 per cent carbon, 12.67 per cent manganese, 8.35 per cent silicon, and 0.1 per cent phosphorus.

TESTING. Tungsten Carbide Cutting Tools in America. *Metallurgist (Supp. to Engineer, Lond.)*, Aug. 30, 1929, pp. 114-115.

Results are given of hardness tests of tungsten-carbide alloy with 6 per cent cobalt and water-toughened manganese steel.

METALLOGRAPHY

Analysis of Sulphur Segregations in Addition to Phosphorus Segregations with Aid of Sulphide Determination (Die Erkennung von Schwefelsteigerungen neben Phosphorsteigerungen mit Hilfe des Sulfidnachweises nach F. Feigl), M. Niessner. *Archiv fuer das Eisenhuettenwesen (Duesseldorf)*, vol. 3, no. 2, Aug. 1929, pp. 157-161, 13 figs. See also *Stahl und Eisen (Duesseldorf)*, vol. 49, no. 38, Sept. 19, 1929, pp. 1378-1379, 2 figs.

Sulphide determination by means of iodine acid reaction according to F. Feigl renders possible analysis even of traces of sulphur in print process of E. Heyn and O. Bauer as well as in process of Baumann.

METALLURGY

Institute of Metals. *Foundry Trade Jl. (Lond.)*, vol. 41, no. 682, Sept. 12, 1929, p. 188.

Review of papers presented before British Institute of Metals meeting, Duesseldorf, covering Aluminum and Its Alloys, A. G. C. Gwyer; Some Methods of Research in Physical Metallurgy, W. Rosenhain; Methods of Research in Metallography, G. Masing; Dilatometric Study of Some Univariant Two-Phase Reactions, P. Chevenard, A. M. Portevin, and X. F. Waché; Open-Air Corrosion of Copper, Chemical Study of Surface Patina, W. H. J. Vernon and L. Whitby, Creep of 80:20 Nickel-Chromium Alloy at High Temperatures, A. G. Lobley and C. L. Betts, and other papers.

The Institute of Metals. *Engineering (Lond.)*, vol. 128, no. 3323, Sept. 20, 1929, pp. 368-369.

Brief discussions of following papers: Reduction of Shrinkage Cavities and Vacuum Melting, W. J. P. Rohn; Progress in Electric Furnaces for Non-Ferrous Metals, M. Tama; Pinholes in Cast-Aluminum Alloys, N. F. Bugden; Properties of Locomotive Firebox Stays and Plates, O. F. Hudson, T. M. Herber, F. E. Ball and E. H. Bucknall; Effect of Temperatures Attained in Overhead Transmission Cable, A. Zeerleider and P. Bourgeois.

The Institute of Metals. *Engineer (Lond.)*, vol. 148, no. 3846, Sept. 27, 1929, pp. 323-325.

Account of meeting held at Duesseldorf, with brief reviews of some of papers read;

methods of research in physical metallurgy; German view of metallographic research; dilatometric studies; corrosion problems; electric-furnace melting, etc.

What a Heat Treater Should Know About Metallurgy, G. M. Enos. *Fuels and Furnaces*, vol. 7, no. 10, Oct. 1929, pp. 1521-1525, 1 fig.

Discussion of fundamental information which heat treater should have so that when occasion arises he may be better able to cope with problem.

The Institute of Metals. *Metal Industry (Lond.)*, vol. 35, no. 11, Sept. 13, 1929, pp. 245-246 and 255-256.

Abstracts of papers presented before Duesseldorf meeting of Institute of Metals; Some Methods of Research in Physical Metallurgy, W. Rosenhain; Dilatometric Study of Some Univariant Two-phase Reactions, P. A. Chevenard, A. M. Portevin and X. F. Wache; Studies on Crystallization of Gold from Liquid State, C. O. Bannister; Properties of Locomotive Firebox Stays and Plates, O. F. Hudson, T. M. Herbert, F. E. Ball and E. H. Bucknall.

Outline of Metallurgical Practice, C. R. Hayward, N. Y., D. Van Nostrand Co., 1929. 612 pp., illus., diagrs., tables. $7.50.

Concise account of modern methods of extracting and refining common metals, their sources, uses, and important alloys; intended for use as quick reference book, and to assist beginning students by giving them rapid survey of current practice which will guide their thinking during study of more elaborate works; supplementary readings are suggested throughout. Eng. Soc. Lib., N. Y.

RESEARCH. International Metallurgy. *Metallurgist (Supp. to Engineer, Lond.)*, Sept. 27, 1929, pp. 129-130.

Remarks inspired by meeting of Institute of Metals at Duesseldorf and of Deutsche Gesselschaft fuer Metallkunde; great question arises whether beneficial results are secured to adequate extent by occasional holding of foreign meetings; great amount of work could be done far better by international cooperation; suggestion was put forward by Rosenhain that small preliminary committee on international collaboration in regard to metallurgical research should be formed immediately; Institute of Metals is in specially favorable position to foster such movement.

METALS

COHESION. Cohesion and Atomic Structure, S. Dushman. *Am. Soc. Testing Matls.—Proc.*, vol. 29, part 2, 1929, 58 pp., 15 figs.

While theory of cohesion in solids based upon atomic structure has not yet been formulated, it is possible to calculate magnitude of cohesive forces by introducing plausible assumptions regarding laws of attraction and repulsion between atoms; cohesive forces calculated on basis of this theory are found to be from ten to one hundred times greater than rupture strengths actually observed.

Intercrystalline Cohesion Theory of Metals (Une théorie de la cohesion intercristalline des métaux). *Science et Industrie (Paris)*, no. 188, Sept. 1929, pp. 593-594, 3 figs.

Application and explanations of phenomenon of tempering through cold working; conclusions which can be drawn from certain properties of crystalline aggregates.

CRYSTALLIZATION. Technical Problems in the Solidification of Metals (Technische Probleme bei der Erstarrung der Metalle), G. Masing. *Zeit. fuer Metallkunde (Berlin)*, vol. 1, no. 9, Sept. 1929, pp. 282-284 and (discussion) pp. 285-286, 1 fig.

Notes on stem crystallization, piping, porosity, and shrinkage; direct and reversed segregation.

DILATOMETRIC EXAMINATION. Analyse dilatometrique des matériaux, P. Chevenard. Paris, Dunod, 1929, 79 pp. illus., diagrs., 25,50 fr.

Author discusses value of dilatometric method in study of thermal changes in metals, describes apparatus and methods that he has evolved at Imphy steelworks, and gives some of interesting results that he has obtained in studying quenching of aluminum bronze, graphitization of cast iron, firing of refractories, and other industrial processes. Eng. Soc. Lib., N. Y.

ELASTIC LIMIT. Determination of Elastic Limits of Metals (Determinacao dos imites de elasticidade do metaes), A. F. Torres. *Boletim Instituto del Engenhario (Sao Paulo)*, vol. 10, no. 49, June 1929, pp. 263-267, 2 figs.

Deformation diagrams; flow limit, resistance limit, proportional limit and elastic limit; limit of commencement of large permanent deformations; tabular results of tests; bibliography and extracts in German, French, and English; illustrations of testing apparatus. Read before Polytechnical School in Sao Paulo.

FERROUS VS. NONFERROUS. Steel Versus Other Metals Especially Light Metals (Stahl kontra andra metaller, speciellt lattmetaller). *Teknisk Tidskrift (Stockholm)*, vol. 59, no. 13, Mar. 30, 1929, pp. 178-186, 5 figs.

Several light metals are compared to steel from physical and economic viewpoint; author brings out fact that world production of aluminum is only 0.21 per cent of steel production and that it grows at rate of 0.01 per cent per year.

GAS CONTENT. Gases—Metals—Alloys (Gase—Metalle—Legierungen), W. Claus. *Giesserei (Duesseldorf)*, vol. 16, nos. 42 and 43, Oct. 18 and 25, 1929, pp. 976-981 and 1000-1003, 16 figs.

Problems of melting and casting are taken up; reversible and irreversible gas-dissolving phenomena in molten metals; law of solubility; gas separation; gas porosity as function of degree of saturation; speed of cooling; solidification and diffusion; deoxidation, desulphurization and decolorization. Bibliography.

MACHINABILITY. Methods of Tests for Determining the Machinability of Metals in General, with Results, O. W. Boston. *Am. Soc. Steel Treating*—TRANS., vol. 16, no. 6, Nov. 1929, pp. 659-694 and (discussion) 694-710, 54 figs.

Results of experiments on 18 ferrous and

21 non-ferrous metals are presented to indicate best methods for determining whether or not material is suitable for machining purposes; it is shown that Brinell number varies almost directly with physical properties of these metals, such as ultimate strength in tension, compression, and shear, as well as Rockwell hardness number; scleroscope values, however, show independent relation.

STRUCTURE. The Inner Crystal Structure of Some Native Metals, H. C. H. Carpenter. *Instn. of Min. and Met.—Trans. (Lond.)*, vol. 38, 1928, pp. 365-386 and (discussion) 386-405, 36 figs. on supp. plates.

Properties of metals and alloys are properties of component crystals; change of crystal form produces change properties; copper, silver, gold, antimony, bismuth, platinum and meteoric iron studied. See Engineering Index, 1928, p. 1153.

TEMPERATURE EFFECT. Creep Limit Alters Technique in Design of Large Tanks, J. K. Wood. *Chem. and Met. Eng.*, vol. 36, no. 10, Oct. 1929, pp. 610-613, 1 fig.

Discussion of creep limit, or degree to which metal can be stressed for prolonged period without permanent set, at definite high temperature; in cracking of oil, containers 40 ft. long and 10 ft. in diam. must withstand pressures as high as 600 lb. and temperatures up to 950 deg. fahr.; codes of design sanctioned by governmental bodies and applied by their inspectors are entirely out of line with new principles upon which design of such tanks should be based.

X-RAY ANALYSIS. Materials Testing with X-Ray Analysis at the Foundry Technical Exhibition at Duesseldorf (Die Werkstoffpruefung mit Roentgenstrahlen auf der Fachausstellung in Duesseldorf), R. Berthold. *Giesserie Zeitung (Berlin)*, vol. 26, no. 19, Oct. 1, 1929, pp. 555-559, 10 figs.

Review of exhibits of methods and apparatus of X-ray analysis, from which impression is gained that analysis of structure of metals has become valuable testing medium in many works; there were no outstanding improvements in X-ray apparatus.

METALS CORROSION

Effect of Oxidizing Conditions on Accelerated Electrolytic Corrosion Tests, Henry S. Rawdon and W. A. Tucker. *U. S. Bur. of Standards—Jl. of Research*, vol. 3, no. 3, Sept. 1929, pp. 375-390, 10 figs.

Accelerated electrolytic corrosion tests were made on sheet copper and nickel in sodium-chloride solution; both anode and cathode were of same metal, and applied emf was relatively very low; results are expressed as loss-of-weight-potential curves; results clearly show that accelerating effect of oxygen on corrosion by reducing potential necessary for given corrosion rate.

METALS CORROSION ANALYSIS

New Methods of Direct and Immediate Determination of Metal Corrosion (Neues Verfahren zur unmittelbaren und sofortigen Ablesung der Metallkorrosion), F. Toedt. *Waerme (Berlin)*, vol. 52, no. 42, Oct. 19, 1929, pp. 796-797.

Method is described according to which corrosion is determined by simple strong-current measurement; by this means immediate determination of corroding and sealing properties of solutions, such as boiler feedwater, and control of dissolved oxygen in air, is possible.

Rust and Depolarization (Der Einfluss der Depolarisation auf die Rostgeschwindigkeit und ihre praktische Nutzanwendung), F. Toedte. *Korrosion and Metallschutz (Berlin)*, vol. 5, no. 8, Aug. 1929, pp. 169-174.

Since oxygen has depolarizing effect on most metal surfaces as well as on that of cathodic iron, it should be possible to measure rate of corrosion of metal; method described has advantage over potential measurements of giving direct indication of amount of corrosion of sample; it is anticipated that much time can be saved by using method in study of corrosion of iron, steel, and alloys, and in evaluation of protective coatings.

METALS CORROSION PREVENTION

Inhibitors as a Means of Reducing Corrosion, E. L. Chappell. *Chem. and Met. Eng.*, vol. 36, no. 9, Sept. 1929, p. 539.

Development of new commercial uses for acid solutions containing inhibitors; review of various articles dealing with subject; function of inhibitors.

METALS FATIGUE

Some Results of Fatigue Tests of Metals, A. Ono. *Soc. Mech. Engrs.—Jl. (Tokyo)*, vol. 32, no. 148, Aug. 1929, pp. 331-341, 10 figs.

Two different kinds of repeated stress experiments were made subjects of present note; one experiment refers to cast iron, of which fatigue resistance under repeated tensile stress was compared with that under repeated bending stress; another experiment refers to fatigue resistance of steel under repeated bending stress applied with or without simultaneous action of steady torsional stress; these experiments show that stress at point of material can not be taken as criterion of strength; nature of fatigue failure is briefly discussed to elucidate results of experiments. (In English.)

The Fatigue of Metals—A Review of Progress from 1920 to 1929, H. F. Moore. *Am. Iron and Steel Inst.—Advance Paper*, for mtg., Oct. 25, 1929, 24 pp., 10 figs.

Results of various investigations regarding fatigue of metals; determining endurance limit; short-time tests; repeated stress testing machines and specimens; effect of understress and overstress on fatigue strength; endurance limit and ratio; importance of localized stress; fatigue of metals at elevated temperatures; heat treatment and fatigue strength; corrosion fatigue; correlation between endurance limit and other physical properties; fatigue strength of cold-worked metal.

The Work of Rupture in Relation to Fatigue. *Metallurgist (Supp. to Engineer, Lond.)*, Aug. 30, 1929, pp. 124-125.

Review of work by K. Ljungberg, main feature of which is discovery that work per unit volume required to fracture specimen at any particular section is constant, irrespective of whether work is applied in single stage or number of stages.

Die Dauerpruefung der Werkstoffe, O.

Foppl, E. Becker and C. V. Hoydekampf. Berlin, Julius Springer, 1929, 124 pp., illus., diagrs., 9,50 r.m.

Discussion of apparatus and method for determining fatigue of metals subjected to vibration; variety of testing machines is described, their uses explained and methods of testing given, together with some results. Eng. Soc. Lib., N. Y.

METALS RESEARCH

Current Metallurgical Research at the Bureau of Standards, H. S. Rawdon. *Metals and Alloys*, vol. 1, no. 4, Oct. 1929, pp. 144-152, 20 figs.

Research projects completed in Metallurgical Division; high-temperature properties of commercial alloy steels; projects supported from other departments, including duralumin and magnesium and lead-base babbitts; projects solely on Bureau funds, including blistering of cast iron on enameling, deep-drawing steel, iron-nitrogen system, hot aqueous quenching media, finish turning of metals, rubber binders for foundry cores, properties of pure metals, resistance of metals to severe service conditions.

METALS TESTING

HIGH TEMPERATURES. Plan of Research on Effect of High Temperatures on Alloys (Projet d'organisation générale des recherches sur la tenue à chaud des alliages), A. Michel. *Revue de Métallurgie (Paris)*, vol. 26, no. 8, Aug. 1929, pp. 447-450.

Author emphasizes importance of study of steels and alloys at high temperature and outlines scheme of research which he recommends.

NICKEL STEEL

Low-Expansion Nickel Steel, T. F. Russell. *Engineering (Lond.)*, vol. 128, no. 3324, Sept. 27, 1929, pp. 400-402, 8 figs.

Examination of two theories put forward to explain low-expansion anomaly, and to see to what extent characteristics of 36-per cent nickel steel may be anticipated from known behaviour of iron or mild steel; conclusions based on tests.

SPECIFICATIONS. Standard Specifications for Structural Nickel Steel. *Am. Soc. Testing Matls. Standards—Supp.*, 1929, pp. 16-21, 2 figs.

Specifications cover; process; discard; chemical composition; ladle analyses; check analyses; tension tests; modification in elongation; character of fracture; bend tests; drift tests; test specimens; number of tests; permissible variations; marking, inspection; rejection; rehearing; tests of eyebars.

NITRIDATION

Nitrogen Surface Hardening. *Metallurgist (Supp. to Engineer, Lond.)*, Sept. 27, 1929, pp. 139-140.

Review of articles in current engineering periodicals; original nitriding process, as set forth by Fry, involves treatment of steel containing chromium and aluminum in ammonia for 90 hours at 510 deg., or not ex ceeding 580 deg. cent.; McQuaid pointed out that addition of small quantity of molybdenum to steel materially reduced notch brittleness of nitrided part; application of nitriding process to motor cylinders and liners; Homerberg recently determined hardness of nitrided surfaces at elevated temperatures.

Influence of Nitrogen on Special Steels and Some Experiments on Casehardening with Nitrogen, S. Satoh. *Am. Inst. Min. and Met. Engrs.—Tech. Pub.*, no. 260, 1929, 19 pp., 20 figs.

Notes on tests, with current of ammonia gas at 580 deg. cent. and at 560 deg., on electrolytic iron, iron alloys, and specially prepared steels; effects of carbon, chromium, aluminum, titanium, manganese, molybdenum, zirconium, and of uranium; effect of nickel on penetration of nitrogen in electric arc welding. Bibliography.

Present Status of Nitrided Steels, H. A. De Fries. *Iron Age*, vol. 124, no. 13, Sept. 26, 1929, pp. 841 and 874.

Five different grades of chromium-molybdenum-aluminum steel now produced by Krupp in Germany for nitriding; manufacture and properties of Nitralloy, preliminary heat treatment, hardening practice, applications, and expected developments are discussed; hardening and drawing before machining; simple equipment required for nitriding operation; outlets in automotive and steam industries.

NONFERROUS METALS

LIGHT. Engineering Values of Aluminum, Magnesium, and Other Light Metals (Die technischen Werte von Aluminium, Magnesium und anderen Leichtmetallen). *Zeit. fuer die gesamte Giessereipraxis (Berlin)*, vol. 50, no. 30, July 28, 1929, pp. 117-118.

Compilation of results of research on durability, resistance to water, mechanical strength, etc., of light metals.

Manufacture and Use of Light Metals (Herstellung und Verwendung von Leichtmetallen), R. Arndt. *Elektrotechnische Zeit. (Berlin)*, vol. 50, no. 37, Sept. 12, 1929, pp. 1332-1334, 5 figs.

Classification of light metals according to density, melting point, and boiling point; table showing production and prices in various countries from 1913 to 1927; maps showing location of German and United States plants. Abstract of paper read before Society of German Chemists in Munich.

OIL-WELL DRILLING EQUIPMENT

HEAT TREATMENT. Heat-Treating in a Western Shop. *Am. Mach.*, vol. 71, no. 17, Oct. 24, 1929, p. 703, 5 figs.

Accurate methods of heat treating and testing high-speed oil-well drilling apparatus are illustrated in five halftones from Doheny Stone Drill Co., Torrance, Calif., each halftone being accompanied by brief explanation.

PICKLING

Acid Test in the Pickling Process (Saeurepruefung im Beizereibetrieb), F. Eisenkolb. *Stahl und Eisen (Duesseldorf)*, vol. 49, no. 32, Aug. 8, 1929, pp. 1162-1164, 1 fig.

Differences between pickling with hydrochloric and sulphuric acids are pointed out; methods of rapid determination of arsenic,

and measurement of free acid in pickling baths are described.

Pickling of Carbon-Poor Ingot Steel sheets (Untersuchungen ueber das Beizen von kohlenstoffarmen Flusstohlblechen), P. Bardenheuer and G. Thanheiser. *Stahl und Eisen (Duesseldorf)*, vol. 49, no. 33, Aug. 15, 1929, pp. 1185-1192, 11 figs.

Review of literature on theories of blister formation due to pickling; diffusion of hydrogen during pickling; influence of thickness of sheet, temperature, nature and concentration of pickling acid, etc.; influence of pretreatment and quality of material on its tendency to form blisters.

PIPE, STEEL

SPECIFICATIONS. Standard Specifications for Lap-Welded and Seamless Steel Pipe for High-Temperature Service. *Am. Soc. Testing Matls. Standards — Supp.*, 1929, pp. 58-63.

Specifications cover: scope; process; ladle analysis; check analyses; tension tests; hydrostatic tests; flattening tests; bend tests; test specimens; number of tests; retests; weights and dimensions; permissible variations; lengths; ends; finish; marking; inspection; rejection.

RAILS

MANGANESE STEEL. Manganese and the Rail Wear Problem. *Ry. Engr. (Lond.)*, vol. 50, no. 598, Nov. 1929, pp. 423-424.

Notes on advantages of including adequate percentage of manganese in steel rails; higher-manganese rail experiments; cost of modified analysis.

PROPERTIES. Steel for Rails (Acos Para trilhos), J. B. da Costa Pinto. *Boletin do Instituto de Engenharia (Sao Paulo)*, vol. 10, nos. 50 and 51, July and Aug., 1929, pp. 40-48 and 75-77.

July: Quotes M. H. W. Belssap of Interstate Commerce Commission on breakage of rails causing 2762 accidents and loss of 775 lives during 12 years; discussion of proper selection of steel; characteristics of steel processes. Aug.: Hadfield process and its advantages; statistical data on steel production, 1913 and 1926; note on experimental rails rolled from steel made in electric furnace.

TRANSVERSE FISSURES. Recent Developments in the Detection of Transverse Fissures in Rails, C. W. Gennet, Jr. *Ry. Eng. and Maintenance*, vol. 25, no. 10, Oct. 1929, pp. 430-433, 5 figs.

Acceptance of detector car for locating and recording fissures in rails by rail committee of American Railway Engineering Association; description of methods employed in detecting rail fissures.

SHEET STEEL

HEAT TREATMENT. Continuous Heat Treatment of Sheet Metal, E. S. Lawrence. *Blast Furnace and Steel Plant*, vol. 17, no. 10, Oct. 1929, pp. 1497-1499 and 1504, 4 figs.; see also *Heat Treating and Forging*, vol. 15, no. 10, Oct. 1929, pp. 1296-1298 and 1306, 4 figs.

Open annealing in continuous heat treatment of sheet metal is discussed with reference to modern furnace equipment; present equipment for box anneal; continuous open annealing defined; advantages of new continuous equipment; qualities of treated sheets; strip-steel treatments. (Continuation of Serial.)

TESTING. The Avery Sheet Metal Testing Machine. *Mach. Market (Lond.)*, no. 1510, Oct. 11, 1929, p. 937, 1 fig.

Description of machine produced by W. and T. Avery, Birmingham, for testing ductility of sheet metal and its suitability for machining, press work and general manufacturing; values of ductility and workability determined separately.

SILICON STEEL

SPECIFICATIONS. Standard Specifications for Structural Silicon Steel. *Am. Soc. Testing Matls. Standards—Supp.*, 1929, pp. 22-26, 1 fig.

Specifications cover: process; discard; chemical composition; ladle analyses; check analyses; tension tests; modifications in elongation; modifications in reduction of area; bend tests; test specimens; number of tests; permissible variations; finish; marking; inspection; rejection; rehearing.

STAINLESS STEEL

The Early History of Stainless Steel, P. R. Kuehnrich. *Foundry Trade Jl. (Lond.)*, vol. 41, no. 682, Sept. 12, 1929, pp. 185-186. See also editorial in no. 219, Sept. 26, p. 219.

Actual history of development of stainless steels is traced and notes on stainless-steel cutlery manufacture also given. Translated from Solingen Tageblatt.

Chrome-Nickel Stainless Alloys, T. H. Nelson. *Iron Age*, vol. 124, no. 14, Oct. 3, 1929, pp. 887-890, 6 figs.

Chemical and physical properties of chrome-nickel stainless alloys, and their applications in chemical field are discussed; chromium is real corrosion resistant in stainless steels; patent situation; chromium-iron brittle range; general working instructions for forging, annealing, pickling, and casting nickel-chromium alloys; alloy foundry's problems today. (Concluded.)

BRAZING AND WELDING. Solder for Rustless Steel. *Iron and Coal Trades Rev. (Lond.)*, vol. 119, no. 3214, Oct. 4, 1929, p. 515.

Difficulties of soldering are due principally to high chromium contents of such steels; well-known soldering alloys are liable to chemical attack at solder joints; notes on composition of alloys which are most suitable; mixture of borax and boracic acid is most suitable flux; others are mentioned. Abstract translated from Metallboerse.

STEEL

TEMPERATURE EFFECT. Steam Pipe Lines of the Issy-les-Moulineaux Central Station and High-Temperature Resistance of Steels Employed (La tuyauterie de vapeur de la Centrale d,Issy-les-Moulineaux et les caractéristiques à chaud des aciers), G. Dessus. *Revue de Métallurgie (Paris)*, vol. 26, no. 8, Aug. 1929, pp. 444-446.

Results of experiments carried out to test behavior of steel employed at temperature of 450 deg. Cent.

COLD WORKING. Study of Strength

and Structure of Cold-Rolled and Annealed Strip Steel with Different Heat Treatments (Festigkeits und Gefuegeuntersuchungen an kaltgewalzten und gegluehten Bandstaehlen verschiedener Vorbehandlung), A. Pomp and H. Poellein. *Archiv fuer das Eisenhuettenwesen (Duesseldorf)*, vol. 3, no. 3, Sept. 1929, pp. 223-231, 17 figs.

Influence of cold rolling with different pressure distributions on strain hardening (tensile strength, elongation and hardness) and on structure of strip steel of increasing carbon content and of different structures; influence of annealing; practical conclusions

PROTECTIVE COATINGS. Protection of Steel Parts against Oxidation at High Temperatures. O. I. Ver and N. V. Agheyev. *Journal Prikladnoy Chimiyi (Leningrad)*, vol. 2, no. 4, 1929, pp. 451-456, 6 figs.

Report from Leningrad Institute of Metals on original experimental studies; 25-hour treatment at temperatures from 900 to 1000 deg. Cent. with mixture consisting of 49 per cent FeAl, 49 per cent aluminum oxide, 2 per cent ammonium chloride makes diffusion deeper than that obtained by calorization or other methods. (In Russian.)

MAGNET. Testing of Permanent Magnet Steel (Die Pruefung von Dauermagnetstahl), W. Oertel. *Stahl und Eisen (Duesseldorf)*, vol. 49, no. 40, Oct. 3, 1929, pp. 1449-1454, 8 figs.

Brief description of commonly used magnet-testing equipment and their defects; details of operation and calibration of new apparatus developed by Bosch, and results obtained; comparative tests with different apparatus on same magnet-steel specimens.

STEEL ANALYSIS

POTENTIOMETRIC. Application of Potentiometric Measurement Analysis in Iron and Steel Laboratory, Especially for the Determination of Manganese, Chromium, and Vanadium in Presence of One Another in Steel (Die Anwendung der potentiometrischen Massanalyse im Eisenhuettenlaboratorium, etc.), P. Dickens and G. Thanheiser. *Archiv fuer das Eisenhuettenwesen (Duesseldorf)*, vol. 3, no. 4, Oct. 1929, pp. 277-290 and (discussion) 290-291.

Nature of potentiometric titration is discussed and examples are given of three methods most commonly used; review of literature.

VANADIUM DETERMINATION. A Rapid Method for Determining Vanadium in Unalloyed and in Alloyed Steels (Eine Schnellmethode zur Bestimmung von Vanadin in Unlegierten and Legierten Staehlen), K. Ries. *Chemiker-Zeitung (Koethen)*, vol. 53, no. 54, July 6, 1929, pp. 527.

Method is described.

STEEL DEFORMATION

Déformations permanentes et ruptures des aciers, P. Régnauld Paris, Dunod, 1929, 90 pp., 23, 30 fr.

Book brings together work of various investigators upon effect of permanent deformations and sudden shock on strength of steel; formation of permanent deformations and ruptures that these may cause, effect of shock, and stability of equilibrium of deformed steel are discussed. Eng. Soc. Lib., N. Y.

STEEL EMBRITTLEMENT

Embrittlement of Steel (Sur la fragilité des aciers), G. d'Huart. *Science et Industrie (Paris)*, nos. 188 and 189, Sept. and Oct. 1929, pp. 559-569 and 636, 58 figs.

Sept.: Embrittlement due to heat treatment either with or without deformation of structure is studied; influence of heat treatment and of age; carbon-steel diagrams, heat-treatment curves, etc., are given. Oct.: Errors from casting and chemical composition of metals due to method of treatment in furnace.

STEEL HARDENING

Hardening and Super-Hardening. *Can. Machy. (Toronto)*, vol. 40, no. 20, Oct. 3, 1929, pp. 49-50.

Description of Cloudburst method of hardening and superhardening steel recently developed by E. G. Herbert; possibilities of useful application of Hultgren's original method and of Herbert's extension of it; explanation found in mechanism of crystalline slip; plastic formation is applied in exceedingly local manner only to thin layer of metal adjacent to surface. From The Engineer.

STEEL HEAT TREATMENT

Steel Treaters Discuss Important Problems. *Machy. (N. Y.)*, vol. 36, no. 2, Oct. 1929, pp. 159-160.

Review of Cleveland meeting of American Society for Steel Treating with brief abstracts of papers presented; behavior of carbon steel in quenching discussed by G. V. Luerssen; necessity for uniformity in carbon tool steel, if uniform hardness results are to be expected; improvements in refractory linings for heat-treating furnaces, W. J. Merten; method of non-destructive internal inspection described by E. A. Sperry.

Steel Treaters Study Steel Melting. *Iron Age*, vol. 124, no. 13, Sept. 26, 1929, pp. 827-829.

Review of Special Session on Steel Metallurgy of American Society for Steel Treating with abstracts of papers presented and discussion; Slags Produced in Steel Making, Their Effects on Product and on Process Itself, G. A. Dornin. Production of Electric Steel for Castings, G. Batty; How to Make Good Locomotive Forgings, L. H. Fry; Melting Practice for Three Types of Electric Steel, H. P. Rassbach.

ANNEALING. The Annealing of Steel, H. H. Scotland. *Can. Machy. (Toronto)*, vol. 40, no. 19, Sept. 19, 1929, pp. 76-77, 13 figs.

Phenomena taking place when piece of steel was subjected to heat for purpose of refining its grain structure and annealing metal is illustrated by means of series of photomicrographs accompanied by explanation of each.

STEEL MANUFACTURE

RESEARCH. Oxides in Pig Iron; Their Origin and Action in the Steel-Making Process, C. H. Herty, Jr., and J. M. Gaines, Jr. *U. S. Bur. of Mines*, 1929, 56 pp., 15 figs.

Quantity of unreduced oxides in blast-furnace irons studied ranges from trace to

more than 0.13 per cent; products of different furnaces vary with respect to silicate content; elimination of this oxide material in open hearth; additions of ore, cinder or pig iron generally cause increase in silicate content; effect of variation in silicon content of pig iron on basic open-hearth operation is discussed.

STEEL METALLURGY

The Iron and Steel Institute. *Engineering (Lond.)*, vol. 128, no. 3323, Sept. 20, 1929, pp. 383-385; see also *Engineer (Lond.)*, vol. 148, no. 3845, Sept. 20, 1929, pp. 306-309.

Brief reviews of following papers, including discussions: Crystallization and Segregation in 1.10 per cent. Carbon-Steel Ingots of Smaller Sizes, A. Hultgren; High Elastic-Limit Structural Steels, J. A. Jones; Coalescence of Pearlite, J. H. Whitely; Hardening of Superhardened Steel by Magnetism—Lattice Resonance Hypothesis, E. G. Herbert; Electrical Conductivity of Magnesite and Some Other Refractory Materials in Relation to the Temperature and their Other Properties, E. Diepschlag and E. Wulfestieg.

STEEL METALLOGRAPHY

Transformation of Austenite into Martensite in Hardened Steel (Ueber die unwandlang des Austenits in Martensit in gehaertetem Stahl), E. Scheil. *Zeit. fuer Anorganische und Allgemeine Chemie (Leipzig)*, vol. 183, nos. 1 and 2, Sept. 23, 1929, pp. 98-120, 16 figs.

Report on experimental study made at Dortmund Research Laboratory of Vereinigte Stahlwerke, A. G.; transformation in quenching process and in cooling at room temperature; nature of strains caused by transformation; effect of storage at various temperatures on transformation; effect of annealing process on beginning of transformation.

PEARLITE. Internal Structure of Pearlite (Sur la structure interne du grain de perlite), N. T. Belaiew. *Revue de Métallurgie (Paris)*, vol. 26, no. 8, Aug. 1929, pp. 424-426, 4 figs.

Each grain of lamelar pearlite is formed of alternating layers of ferrite and cementite; these lamelar structures can only be studied micrographically.

STEEL RESEARCH

Notable Progress in Steel Research. *Iron Age*, vol. 124, no. 17, Oct. 24, 1929, pp. 1111-1112. See also *Iron Trade Rev.*, vol. 85, no. 17, Oct. 24, 1929, pp. 1042-1043.

Review of meeting of Metallurgical Advisory Board to Carnegie Institute of Technology and U. S. Bureau of Mines, in Pittsburgh, with abstracts of reports presented; new methods for measuring amount of sonims in steel, reported by C. H. Herty, Jr.; deoxidation of steel with silicon; effect of sonims on seamless tubes; studies by V. N. Krivobok into reasons for random grouping of crystal aggregates after carburizing; standards for abnormal steel; studies of manganese alloys and studies, alloy steels.

STEEL TESTING

Dilatometric Anomalies of Several Extra Mild Steels after Special Heat Treatment (Anomalies dilatométriques de quelques aciers extradoux après un chauffage spécial), J. Seigle. *Génie Civil (Paris)*, vol. 95, no. 15, Oct. 12, 1929, pp. 359-361, 5 figs.

Normal dilatometric curves for mild and extra mild steels; results of tests of Armco steels by American Rolling Mill Co.; tests of electric steels; possible causes of anomalies observed, influence of dissolved gases.

The Relation Between Strength in Repeated Bending and Strength under Static Stresses (Ueber die Beziehungen der Dauerbiegefestigkeit zu den statischen Festigkeitswerten), W. Herold. *V. D. I. Zeit. (Berlin)*, vol. 73, no. 36, Sept. 7, 1929, pp. 1261-1266, 9 figs.

Report on results of series of 160 tests purpose of which was to determine whether value of strength under repeated stresses could be derived from tensile strength of material; various types of carbon, nickel, chromium, manganese and other steels were tested; derivation of general formula expressing relationship.

SPARK METHOD. Practical Aspects of Spark Testing, W. G. Hildorf and C. H. McCollam. *Iron Age*, vol. 124, no. 15, Oct. 10, 1929, pp. 953-956, 4 figs.

Description of method of spark testing employed by Timken Steel and Tube Co., Canton, Ohio, for sorting out steel which has been mixed; thousands of dollars saved by this method; trained spark testers quickly identify different grades of steel by noting characteristics of spark thrown off by grinding wheels; scope and limitations of method outlined; shower of sparks examined in three areas; method of training spark tester; equipment necessary.

High-Elastic-Limit Steel, F. G. Martin. *Iron and Coal Trades Rev. (Lond.)*, vol. 119, no. 3206, Aug. 9, 1929, p. 193.

Author outlined development of high-elastic-limit steel and emphasized difference between elastic limit and yield point; average results from 26 accepted tests for plates and 27 for sections; compression tests; method of testing; behavior of high-elastic-limit mild steel in ship construction. Abstract of paper read before West of Scotland Iron and Steel Inst.

The Creep of Steel at High Temperatures, F. H. Norton. Edition 1. New York, McGraw-Hill, 1929, 90 pp., illus., diagrs., tables, $3.00.

Investigations reported here were carried out at Massachusetts Institute of Technology, at request of Babcock and Wilcox Co.; to provide engineering data on safe stresses for steels at higher temperatures; after reviewing previous methods and results, author describes his apparatus, gives results of investigations of steels at temperatures above 1000 deg. fahr. and discusses his results. Eng. Soc. Lib., N. Y.

Mathematical Relations between Figures Expressing Toughness of Notches Obtained with Various Types of Test Forms (Verhaeltniszahlen zwischen den mit verschiedenen Probenformen erreichten Kerbzaehigkeitszahlen), R. Mailaender and F. P. Filcher. *Kruppsche Monatshefte (Essen)*, vol. 10, July 1929, pp. 99-102, 10 figs.

Comparative curves for carbon and nickel steels, and chromium-nickel steels, obtained from Mesnager and Charpy tests.

News of the Society

SEMI-ANNUAL MEETING AT NEW YORK CITY

ARRANGEMENTS have been completed for the Semi-Annual Meeting of the Society, which will be held in New York City, Friday and Saturday, February 7 and 8, 1930, with headquarters at the Hotel Pennsylvania.

An interesting technical program has been arranged and Chairman W. B. Coleman of the Meetings and Papers Committee has secured seven papers for presentation before three technical sessions to be held on Friday and Saturday. The papers scheduled for presentation are as follows:

Friday Morning

Registration—9:00 A. M.
Technical Session—10:00 A. M.

Nickel Alloy Steel Forgings—By Charles McKnight, International Nickel Co., New York City.

Effect of Chromium Additions to Manganese Structural Steel—By A. B. Kinzel, Union Carbide and Carbon Research Laboratories, Long Island City, N. Y.

Friday Afternoon

Technical Session—2:30 P. M.

A Study of the Grain Structure in Martensite—By E. C. Bain and K. Heindlhofer, U. S. Steel Corporation Research Laboratories, Kearny, N. J.

A Study of the Nitriding Process, Part II—The Simultaneous Introduction of Nitrogen and Carbon—By V. O. Homerberg and J. P. Walsted, Massachusetts Institute of Technology, Cambridge, Mass.

Saturday Morning

Technical Session—10:00 A. M.

Recent Developments in Normalizing Sheet Steel—By Edward S. Lawrence, Duraloy Company, Pittsburgh.

Some Notes on Sheet Metal and Strip Steel for Automobile Bodies—By Joseph Winlock and George L. Kelley, Edward G. Budd Manufacturing Co., Philadelphia.

Metal for Vitreous Enameling—By J. H. Nead, American Rolling Mill Co., Middletown, Ohio.

It will be observed from this schedule that the papers to be presented cover a very broad field and offer a diversity of subjects which will prove both stimulating and instructive to those attending this meeting. None of these papers will be preprinted and the authors will, therefore, be given additional time for presentation and ample time will be allowed for oral discussion.

Meetings of the Board of Directors, Recommended Practice and Publication

Committees will be held on Thursday preceding the Semi-Annual Meeting, with a meeting of the Finance Committee of the Society on Wednesday, February 5, to prepare a budget for the coming year.

Since New York City is so readily accessible to the membership in the Eastern States and just a pleasant trip from the middle west, it is urged that all members who possibly can attend the meeting, do so, as this meeting will prove more than worth while.

THE YORK GROUP

THE first activity resulting in the inauguration of the York Group of the American Society for Steel Treating was begun in April, 1929, with Messrs. G. J. O'Neill, of the Pennsylvania Gas and Electric Co.; W. C. Bulette, of the Brandt-Warner Manufacturing Co.; N. J. Gebert, of the American Chain Co., and C. W. Vogel, of the York Ice Machinery Corp., as the prime movers. A campaign for membership was at once begun, there being excellent opportunity for such a campaign in York and neighboring cities. A meeting was held at which the campaign was outlined, a petition circulated and signatures obtained for a group charter in the American Society for Steel Treating.

In September, 1929, a lecture was given by A. W. F. Green, secretary of the Philadelphia Chapter of the Society, before the Engineering Society of York and prospective members of the York Group of the American Society for Steel Treating were invited to attend. A get-together dinner was held preceding the lecture, at which Messrs. R. C. Jordan, W. B. Coleman, H. B. Allen, and A. W. F. Green, of the Philadelphia Chapter, were in attendance, in addition to a number of local men. At this meeting several new names were added to the petition for group charter and it was decided to forward it to the National Office of the Society in Cleveland. A committee meeting for drafting the petition was dispensed with, and H. F. Ware met the various members separately. In consequence there was some delay, and it was not until October 14 that the petition was finally forwarded. On the same date a preliminary meeting was held and a lecture was given by R. C. Gosreau on the subject of "General Metallurgy of the Ferrous Metals."

The official opening meeting of the York Group was held on November 8, 1929, at which an illustrated lecture was given by George A. Richardson, technical director of publicity, Bethlehem Steel Co., Bethlehem, Pa., on the subject of "General Manufacture of Steel." Mr. Richardson has gained an enviable reputation in the Society as being a forceful and interesting speaker and at York retained his usual reputation as a pleasing and worthwhile lecturer.

Mr. Richardson's talk was followed by a business meeting at which the permission to form a local group was announced. On the evening of November 22 an organization meeting was held and the following officers were elected:

Chairman	George J. O'Neill
Vice-Chairman	R. C. Gosreau
Secretary-Treasurer	Hollis F. Ware
Executive Committee	H. A. Delano, W. C. Bulette, F. H. Lewis, W. A. Tobias and J. J. Curran

A program committee of eight members and a membership committee of fourteen was appointed, with N. J. Gebert and L. O. Buckner as chairmen, respectively.

Much of the success of the group in obtaining members from Harrisburg and Steelton was due to the activity of J. J. Curran, formerly of the Hartford Chapter of the Society, who has since transferred his membership to York.

The following is a partial list of the charter members of the York Group.

William G. Appel
John C. Bennett
Henry A. Brickner
Laurence O. Buckner
Warren C. Bulette
F. J. Bullard
George J. Campbell
J. R. Clendenning
James J. Curran
H. A. Delano
William D. Dohoney
Harry F. Doughtery
Chas. J. Dudley
Glenn Frank
James T. Frank
N. J. Gebert
Frank K. Gosnell
R. C. Gosreau
O. F. Kuhlman
Fred H. Lewis
Wm. E. Martin
Elmer A. Mercner
Chas. H. Moore
James G. Morrison
George J. O'Neill
A. C. Perry
Fredrick E. Reiners
John Senft
G. E. Shubrooks
Chas. M. Strickler
George Szekely
William A. Tobias
C. W. Vogel
Hollis F. Ware
J. M. Washington
R. E. Wentzler
A. Floyd Whalen
Lloyd G. Wheeler
John H. Wiest
Ernest G. Wigfield
Chester M. Woolworth

January

mittee of
chairmen,

Harrisburg
Hartford
to York.

ork Group.

rth